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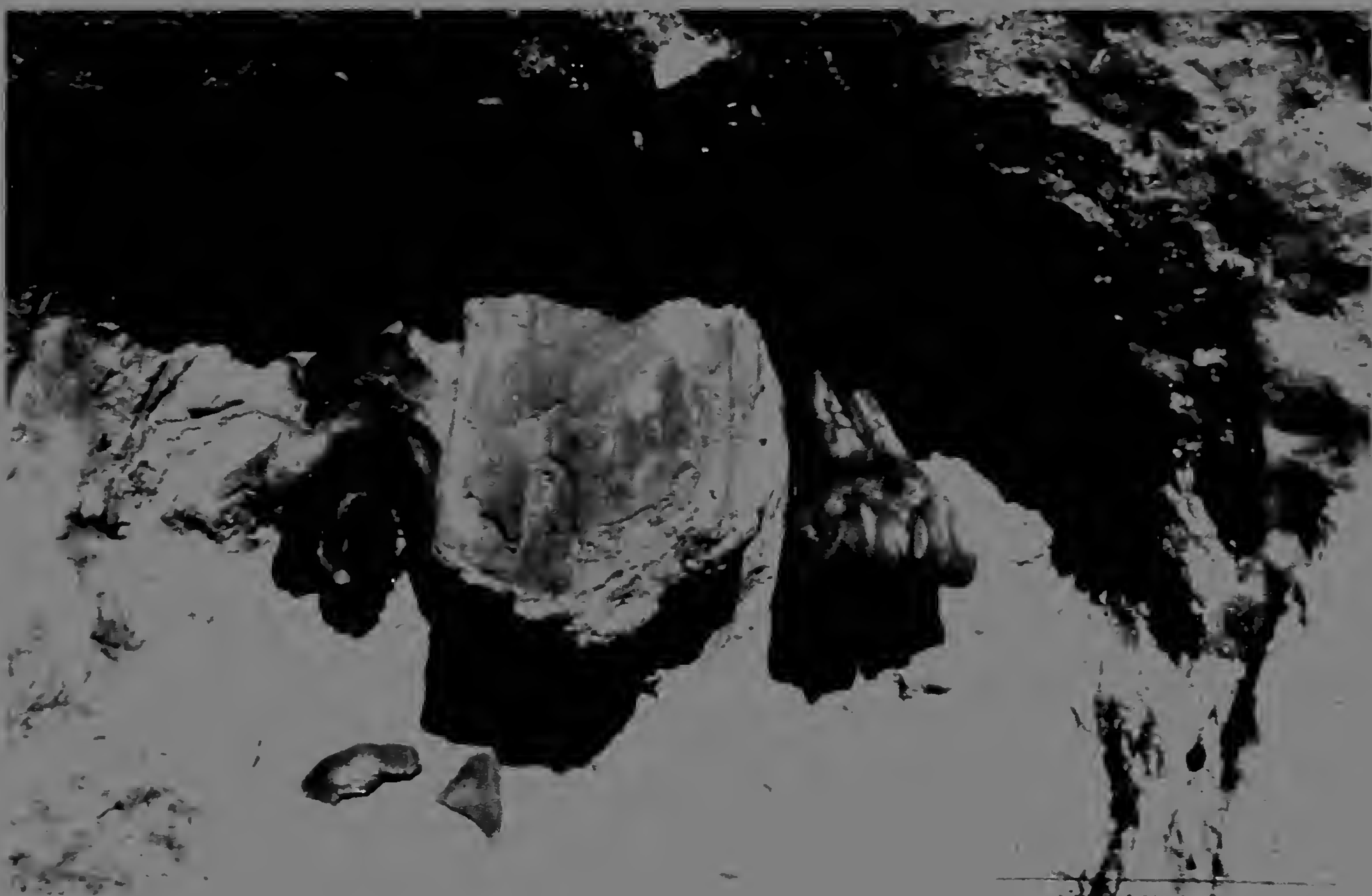

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North Sea Coast

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EDITORIAL

This issue of the Bulletin contains a substantive article by Tim Holt-Wilson that describes the rescue geology undertaken at Shropham in the mid-1990s. The Shropham gravel pits exposed late Pleistocene sediments. some of them highly fossiliferous. I well remember Jimmy Lightwing bringing in his latest finds to GSN meetings at that time. This site has therefore been in the consciousness of the GSN for over 20 years. not least as a site where our database group has arguably had some of its greatest impact. Despite the work that took place by a number of active GSN members there has so far been little documented on the outcomes. which makes this contribution very welcome.

The Bulletin is completed by another excellent 'beachcombing' contribution by Steven Donovan. based on his Holocene finds from the Dutch North Sea coast. Of course today the southern North Sea divides East Anglia from the Netherlands. but we need go back only 20.000 years to a time when Norfolk. as part of 'Greater East Anglia' joined seamlessly to Europe when global sea-level was much lower than today. Although we are pretty much are due another Icê Age. it seems that global warming is likely to delay our reunion to the continent for some time yet

INSTRUCTIONS TO AUTHORS

Contributors should normally submit manuscripts either as word-processor electronic files (MS Word is preferred) or hard copy. When papers are accepted for publication we will request an updated electronic version.

It is important that the style of the paper, in terms of overall format, capitalization, punctuation etc. conforms as strictly as possible to that used in Vol. 53 of the Bulletin. Titles and first order headings should be capitalized, centred and in bold print. Second order headings should be centred, bold and lower case. Text should be 1½ line spaced. All measurements should be given in metric units.

References should be arranged alphabetically in the following style.

BALSON, P.S. & CAMERON, T.T.J. 1985. Quaternary mapping offshore East Anglia. *Modern Geology*, **9**, 221-239.

STEERS, J.A. 1960. Physiography and evolution: the physiography and evolution of Scolt Head Island. In: Steers, J.D. (ed.) *Scolt Head Island* (2nd ed.), 12-66, Heffer, Cambridge.

BLACK, R.M. 1988. *The Elements of Palaeontology*. 2nd Ed., Cambridge University Press, Cambridge. 404pp.

We now make pdf versions of all papers for authors (replacing offprints) and for possible future WWW availability. For this reason we prefer illustrations drawn with a computer graphics package, ideally saved in jpeg format. Thick lines, close stipple or patches of solid black or grey should be used with care as they can spread in printing hard copy. The editor may have diagrams re-drawn professionally and usually the GSN will cover the cost of this. For efficient use of space full use should be made of the width of print on an A4 page when designing diagrams. Half tone photographic plates (if possible reproduced as jpeg files) are acceptable provided the originals exhibit good contrast.

The editors welcome original research papers, notes, comments, discussion, and review articles relevant to the geology of **East Anglia** as a whole, and do not restrict consideration to articles covering Norfolk alone. All papers are independently refereed by at least one reviewer.

BORED BIVALVES, BORING GASTROPODS AND WAY-UP STRUCTURES, NORTH SEA COAST, THE NETHERLANDS

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ABSTRACT

A slab of sandstone, probably a Holocene beachrock, was collected from the North Sea coast of the Netherlands near Zandvoort aan Zee, province of Noord Holland. There are numerous embedded benthic molluscs in this specimen, but of limited specific diversity, namely the bivalves *Spisula elliptica* (Brown) and a rarer cardiacean sp. indet. and the gastropod *Euspira pulchella* (Risso). This association of mainly disarticulated valves of infaunal bivalves is a death assemblage, albeit most probably parautochthonous. The common valves of *S. elliptica* preserve evidence of the 'way-up' of the slab at the time of deposition, being interpreted as preserved concave surface downward. Some valves of *S. elliptica* are perforated by bevelled borings, *Sedilichnus paraboloides* (Bromley), and were probably the prey of predatory *E. pulchella*. *Euspira pulchella* was also a cannibal.

INTRODUCTION

The North Sea coast of the Netherlands is typified by sandy beaches backed with sand dunes. Offshore, Quaternary and Tertiary rocks are exposed which have yielded a diverse association of fossil molluscs (Moerdijk *et al.*, 2010). Although fossil shells are rare in the author's field area north-north-east of Zandvoort-aan-Zee, province of Noord Holland, clasts of Quaternary peat, derived from offshore (Jelgersma *et al.*, 1970, fig. 1), are locally common on the beach, most particularly after storms, and may show evidence of boring by Recent bivalves (Donovan, 2013, 2015).

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Unusually, the author collected a slab of sandstone with numerous embedded benthic molluscs in January 2014, the first I have noted from the collecting site in 10+ years of beachcombing. The shells in this specimen preserve evidence of the 'way-up' of the slab at the time of deposition, predation on one species of bivalve, the probable gastropod predator and cannibalism of the same. All these palaeoecological data, deduced from one chance find, makes this specimen of some broad general interest to geologists, particularly those around the southeastern North Sea. Specimens are deposited in the Naturalis Biodiversity Center, Leiden (RGM), the Netherlands.

LOCALITY

(Abridged from Donovan, 2013, p. 109.) The specimen described herein, RGM 791 629, came from the Zandvoort aan Zee – Bloemendaal aan Zee – Parnassia Strand area, Noord Holland (Donovan, 2015, fig. 1; 1:25,000 topographic map Haarlem 25A). The strandline of this beach is commonly littered with myriad shells, and valves of infaunal and epifaunal invertebrates (Donovan, 2007). It is rare for fragments of submerged Quaternary peats and mudrocks derived from offshore to form part of this assemblage, except after a major storm, and rarer still to find a cobble of sandstone. It is such a clast that forms the subject of the present study.

DESCRIPTION

RGM 791 629 is a slab of medium-grained sandstone with rare, rounded quartz clasts up to *c*. 4 mm diameter. The slab is about 152 x 101 x 27 mm, preserving numerous shells of benthic molluscs only (bivalves, gastropods). Presumably this is reworked from a more extensive bed of, probably, beachrock, that is, a Holocene *strandconcretie* (Moerdijk *et al.*, 2010, p. 43, fig. 36). Molluscs are more numerous as both valves and fragments on one side of the slab (Fig. 1A); most of the larger valves on this side expose the internal surface of the shell and there is some stacking. The other side (Fig. 1D) preserves relatively more shell fragments than identifiable valves; complete valves show mainly the external surface, although some smaller specimens expose the internal surface. Gastropods are rare on both surfaces and show no identifiable preferred orientation.

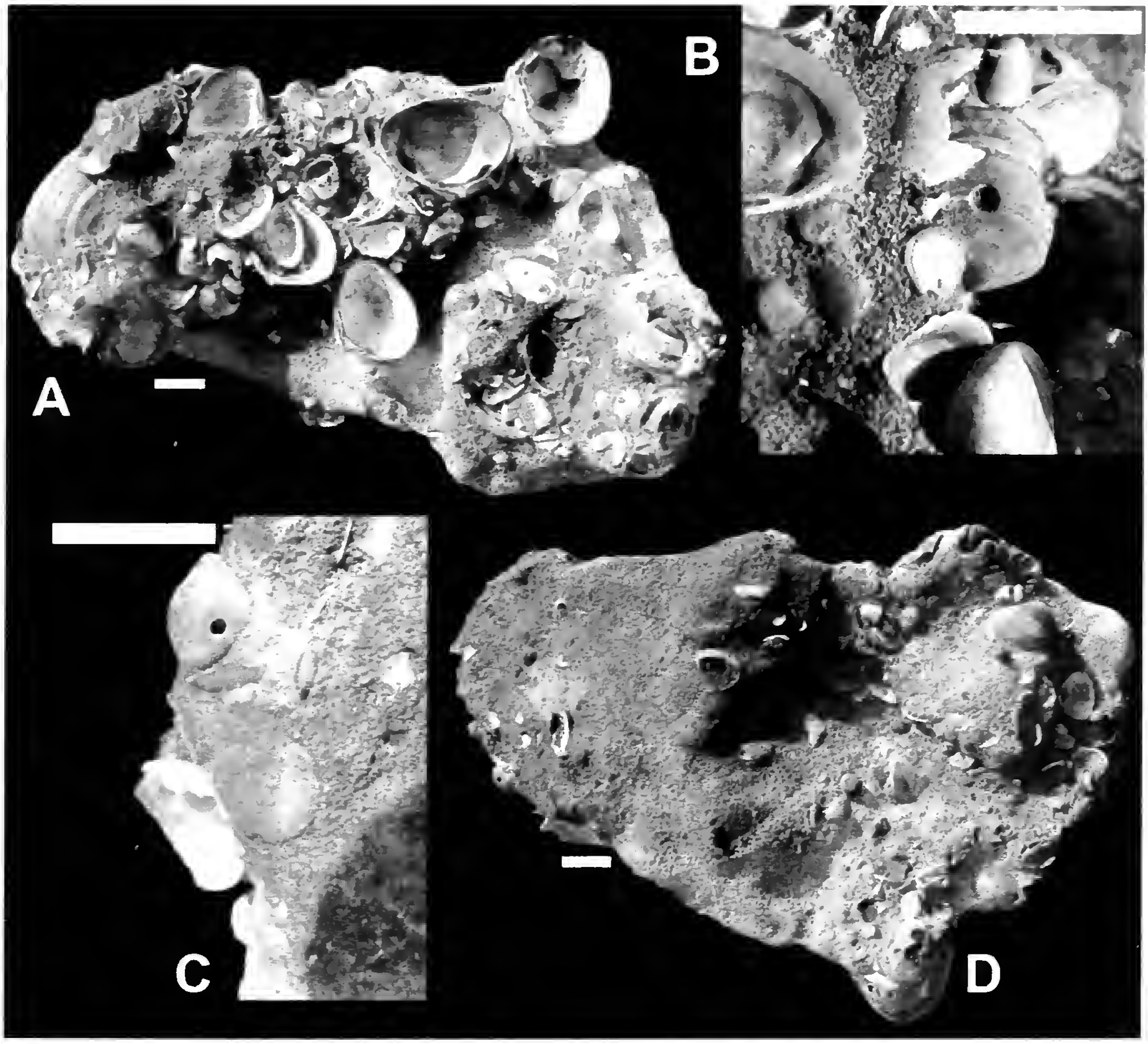

Fig. 1. Slab of mollusc-rich sandstone, RGM 791 629, collected from the beach north-north-east of Zandvoort aan Zee, province of Noord Holland, the Netherlands. (A) Basal surface of slab, showing disarticulated bivalves preserved in concave-up orientation. (B) Bivalves from this surface showing small, conical drillholes, *Sedilichnus paraboloides* (Bromley); the specimen immediately above centre has cracked through the boring (after Donovan and Fearnhead, in press, fig. 2). (C) Boring *Oichnus paraboloides* in naticid gastropod shell (lower left in D). (D) Upper surface of slab, less specimen rich than (A) and with more bivalves preserved both convex- and concave-up. Scale bars represent 10 mm.

The commonest bivalve is a *Spisula* Gray, close to *Spisula elliptica* (Brown) (Tebble, 1976, p. 131, text-fig. 68a, b; Wiese & Richling, 2008; Moerdijk *et al.*, 2010, pp. 254-255, figs 483a, 487, 488). Where identifiable, these are right valves (Fig. 1A, D). Some valves are perforated by single, circular, bevelled drillholes, *Sedilichnus paraboloides* (Bromley) (Fig. 1B). A second, rare bivalve is a cardiacean sp. indet., present as small valves and fragments. Gastropods are limited to a few shells of a naticid, close to *Euspira pulchella* (Risso) (Wiese & Richling, 2008). One of these gastropods also preserves a *Sed. paraboloides* boring (Fig. 1C).

DISCUSSION

All taxa in this specimen of sandstone were infaunal in life. This association, comprised of mainly disarticulated bivalves preserved parallel to bedding, is interpreted as a death assemblage. However, the few species interred are inferred to be essentially parautochthonous because their presumed predators are preserved in close association (see below) and these shells are all known as Recent shells washed up on this part of the coast. As noted above, the commonest shells are the disarticulated valves of *S. elliptica*, which preserve evidence of the 'way-up' of the slab at the time of deposition; typically, disarticulated valves of bivalves are preserved concave surface downward (Ager, 1963, p. 81; Dodd & Stanton, 1981, fig. 7.10; Brenchley & Harper, 1998, pp. 85-90). This is an event concentration, in which "The taxonomic composition, and preservational characters are normally uniform throughout the thickness of the bed, reflecting rapid deposition of a well-mixed population of shell material" (Brenchley & Harper, 1998, p. 85).

Some valves of *Spisula elliptica* preserve evidence of falling prey to an infaunal drilling predator. Those specimens that are perforated by the bevelled drillholes, *O. paraboloides* (Fig. 1B), were probably the prey of predatory gastropods. Although such borings may be produced by a range of organisms (Bromley, 2004, pp. 466-467), the commonest producers of *Sed. paraboloides* are predatory naticid snails (Bromley, 1981, 2004), one of which occurs in this slab, namely *Euspira pulchella*. It is probable that *E. pulchella* was a predator of *S. elliptica*. It is probable that *E. pulchella* was a predator of *S. elliptica*. Borings are all single; no valve shows multiple borings. Further, most borings are on or about the anterior-posterior axis of the valve; only one specimen, poorly seen, appears to have been bored in the umbonal region, suggesting

a preferred area for drilling the shell of the bivalve. The cardiacean sp. indet. shows no evidence of boring, but shells are rare and incomplete, so it is uncertain if they were bored or not.

If this interpretation is correct, then *E. pulchella* was also a cannibal. One specimen of *E. pulchella* (Fig. 1C, D lower left) bears a boring that is referred to *Sed. paraboloides*, presumably produced by a member of its own species (compare with Pickerill & Donovan, 1998, pl. 3, figs 4-7).

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THE BONE BED AT SHROPHAM PIT, NORFOLK - THE RESULTS OF RESCUE INVESTIGATION, 1994

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ABSTRACT

Quarrying in a succession of pits at Shropham, Norfolk, from the 1950s to 1990s revealed sediments containing rich assemblages of vertebrate and other fossils dated to the Ipswichian and Devensian stages of the late Pleistocene. Work conducted in 1994 by the Database Group of the Geological Society of Norfolk enabled the rescue recording of numerous temporary exposures of sedimentary sequences at Manor Farm Pit. Among them was a bone bed containing Ipswichian fossils, and the results of its partial excavation are presented here. The bone bed is interpreted as having been emplaced by a sediment gravity flow in a lacustrine context. The chronostratigraphy, based on results from Royal Holloway College, University of London, show this occurred during the early Devensian. The role of dynamic factors in the depositional environment, including Chalk bedrock dissolution and periglacial diapirism, are explored. Suggestions for future work are proposed.

INTRODUCTION

During 1994 the Database Group of the Geological Society of Norfolk investigated temporary exposures at Manor Farm Pit, a gravel quarry near Shropham, Norfolk, ~5 km WSW of Attleborough, centred on TM 003939 (Fig. 1). This was one of a group of sand and gravel workings in the valley floor of the River Thet (Fig. 2). Sand and gravel extraction had been active in this part of the valley since at least 1956, under the ownership of Minns Aggregates and later Ayton Asphalte Co. Ltd. Manor Farm Pit was being actively worked in 1994, but is now flooded and landscaped. The site is

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currently owned by Breedon Aggregates, and used for processing sand and gravel from their Honeypots quarry elsewhere in Shropham.

Geomorphological and geological context

Manor Farm Pit is located in the upper catchment of the River Thet, which is a tributary of the River Little Ouse that drains westwards into the Fen basin. The present drainage pattern is incised into a gently undulating till plateau landscape, with local high points lying between 50 and 60 m OD. The valley sides west of Manor Farm Pit have a gently sloping cross-profile, with a mean gradient of 30 m per km (3°). The complex of pits at Shropham (Fig. 2) is located where the valley widens at the confluence of three streams, which have headwaters in the parishes of Rockland, Great Ellingham, Attleborough and Hargham. Two river terraces have been identified in the valley: the first lying at 3 m above floodplain level and the second between 5 and 6 m above floodplain level (Mathers *et al.*, 1993 p. 31 and Fig. 3).

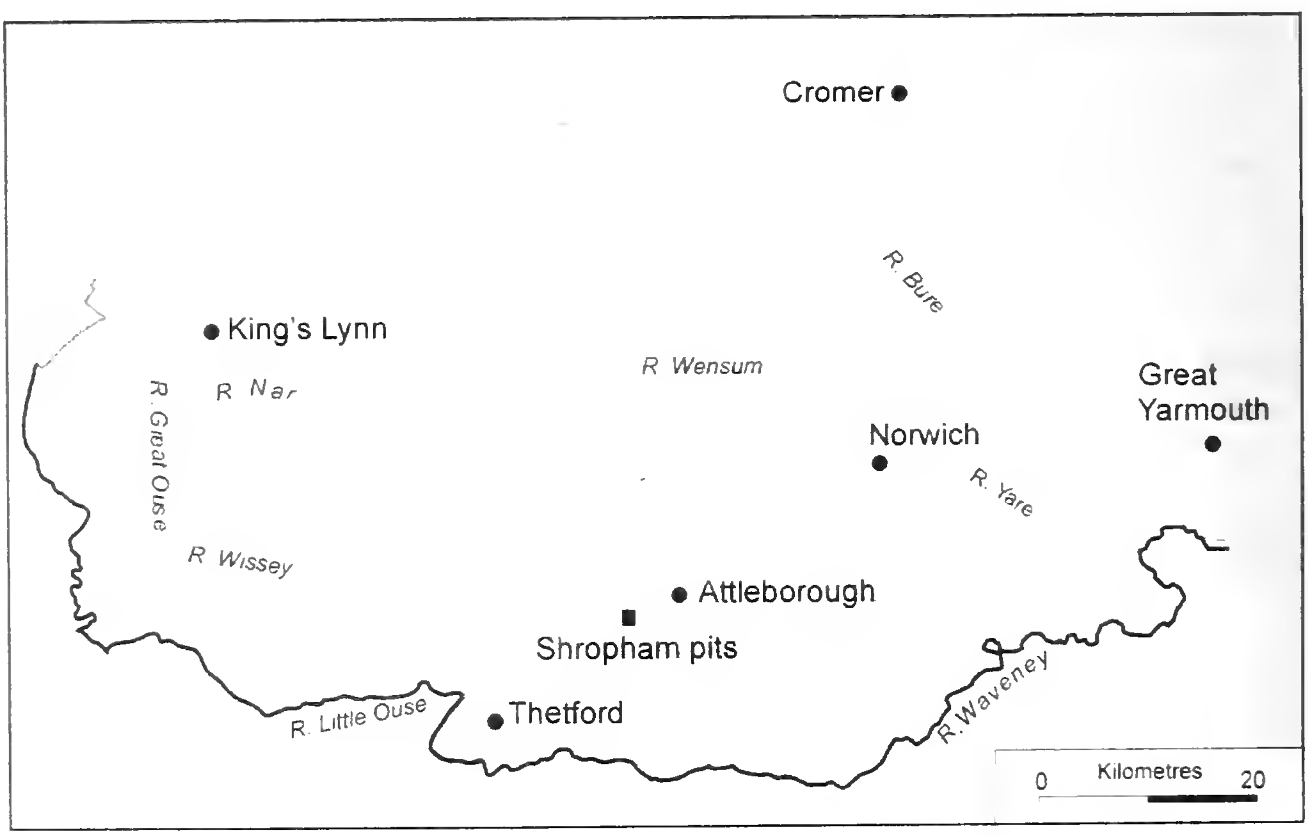

Fig.1. Location of the Shropham pit complex in regional context.

The geology of the Shropham area has been investigated by the British Geological Survey (BGS) (Mathers, 1988; British Geological Survey, 1989). The Thet valley is incised into a complex mosaic of glacial till and glaciofluvial sand and gravel of Anglian age, overlying Upper Chalk bedrock. The buried surface of the Chalk displays considerable local relief, with a boss rising to crop out close to the northern end of Manor Farm Pit and falling away quite steeply (~43 m per km) to the south, where the contours of the chalk surface indicate the presence of a buried channel (British Geological Survey, *ibid*). Such channels form a network in East Anglia, and were carved by subglacial meltwater in Anglian times (Bricker *et al.*, 2012). A well borehole sited ~100 m west of the Pit at TM 0003 9394 (BGS borehole TL99SE15, see Geology of Britain Viewer http://mapapps.bgs.ac.uk/geologyofbritain /home.html), recorded 1.5 m of 'topsoil' and a thin layer (3.1 m) of 'drift' (sticky khaki clay with chalk fragments) overlying Chalk bedrock, at 25.54 m OD. The 'drift' is interpreted as a chalky till attributed to the Lowestoft Formation. The geology of the valley floor is mapped by the BGS as alluvium (silt and clay, sandy in parts), with river terrace deposits (spreads of sand and flint-rich gravel) discontinuously flanking the floodplain (British Geological Survey, *ibid*). Manor Farm Pit was excavated in the sediments of Terrace 1, at c.24 m OD. The geological map shows these terrace deposits banked against the glacial till of the valley side.

HISTORY OF INVESTIGATION

The pits at Shropham have been subject to sporadic investigation by researchers and fossil collectors for over 40 years. The earliest recorded collection of vertebrate material refers to specimens of Ipswichian (Eemian) and Devensian (Weichselian) age, collected in 1956 from an unspecified pit located at 24 m OD, and now deposited in Norwich Castle Museum (McWilliams, 1972). Judging from an aerial photograph dated 1946 (Norfolk Heritage Explorer, 2013), this pit is likely to be the one visible at TM 003940, the earliest in the complex (marked '1946 pit' on Fig. 2). J.D. Clayden of the Geological Society of Norfolk began collecting at Shropham in 1983. Academic researchers visiting the site in the 1980s included A.P. Currant, P.L. Gibbard, D.L. Harrison, J.A. Holman, P.J. Lawrence, R.C. Preece, A.J. Stuart and C.A. Whiteman (J. Clayden, pers. comm.).

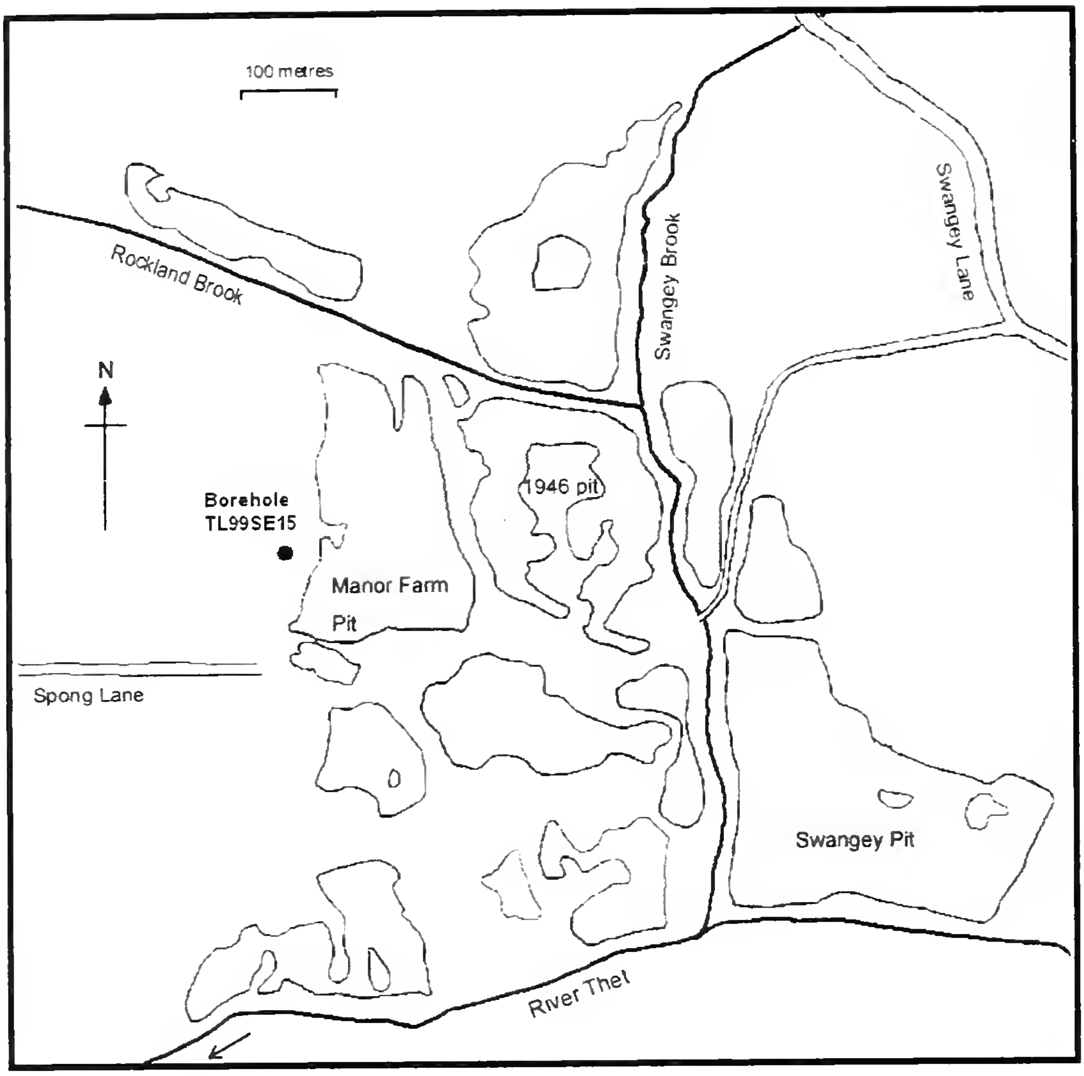

Fig. 2. Location of Manor Farm Pit, Swangey Pit and the 1946 pit within the complex of flooded pits at Shropham, 2012.

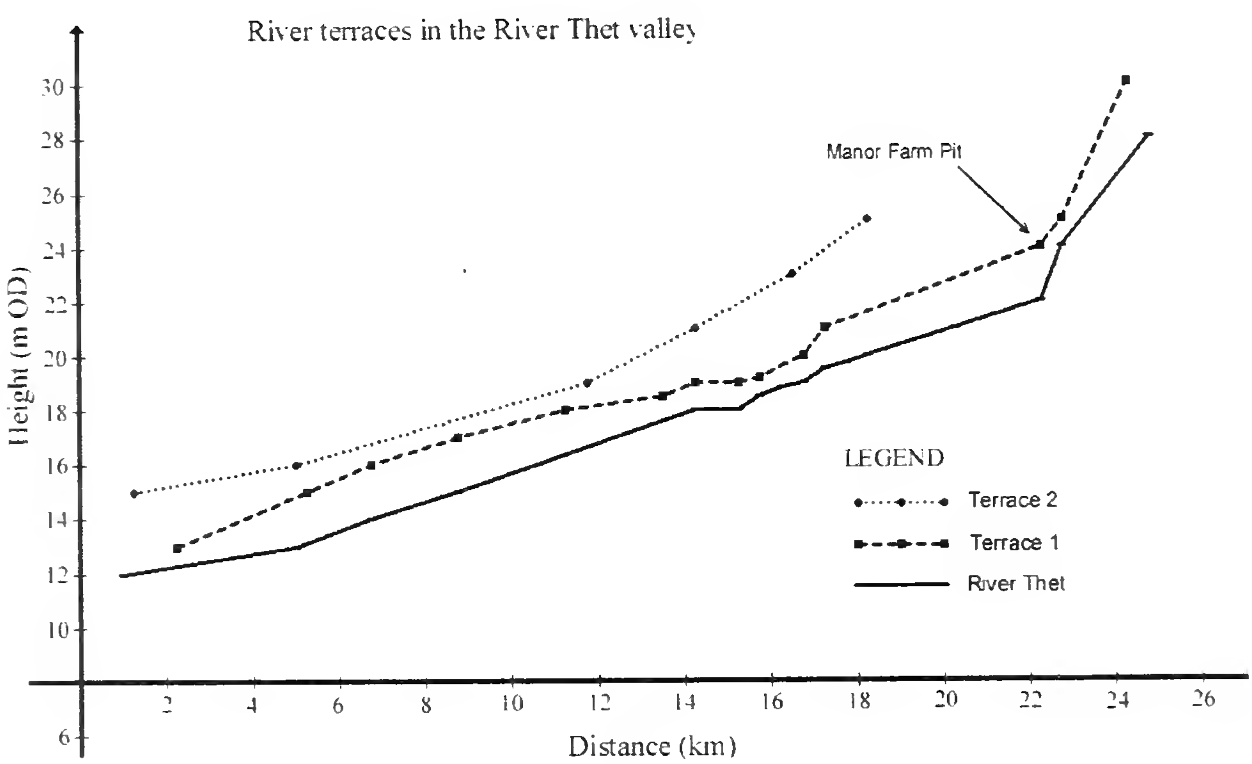

Fig. 3. Long profile diagram showing vertical distribution of river terraces in the River Thet valley, based on published mapping of terrace remnants by the British Geological Survey (1989; 2010).

Shropham had become notable for the exceptional quantity and state of preservation of vertebrate remains. On some occasions in the late 1980s the quantity of bones excavated by the quarry company was so great that it was affecting the quality of the aggregate, and truck loads were said to have been taken and dumped in one of the lakes (A.J. Read, pers. comm.). It was recognised that further work on the stratigraphy was needed. "*Mammalian bones have been found extensively at this locality, although the level from which they derive has not been documented by collectors. Clearly, further investigations are needed at this site to try and establish the age of the organic deposits and the source of the bones*" (Mathers *et al.*, 1993). The pits at Shropham were visited regularly by A.J. Stuart in 1990-1992, and palaeontological material collected at that time is now conserved by the Norfolk Museums Service. An Ipswichian herpetofauna was published from Swangey Pit at TM 005938 (Holman & Clayden, 1990), and a notable cold-phase herpetofauna was identified from a 'Devensian pocket' there (Holman, 1998). A faunal list entitled 'Shropham Interglacial (unpublished)' and dated 24th July 1991 was compiled from specimens in the Norwich Castle Museum and Clayden collections, and is archived at the Museum.

In 1992 a quarry, named herein as the Manor Farm Pit, was opened in the area of TM 001939, and began to yield abundant vertebrate remains, including *Palaeoloxodon antiquus* (Falc. & Caut.), *Bison priscus* Bojanus, *Hippopotamus amphibius* L. and *Emys orbicularis* (L.). In autumn 1993 a skull of *Bison priscus* was excavated from this pit under the direction of A.J. Stuart of the Norfolk Museums Service. Intensive fossil collecting was carried out in 1993 and 1994 by P. Alden, P. Bradshaw, J. D. Clayden, R. Green, J. Lightwing, and A. Thompson. Trial pits were dug and layers on the quarry floor were stripped by hand using spades, forks and trowels; large quantities of sediment were sieved for small vertebrate fossils, particularly by Clayden and Green. Specimens were also collected from the processing area of the quarry; in one instance a partial skull of lion *Panthera leo* was recovered from a conveyor belt to the crushing plant (J. Lightwing, pers. comm.). This work was essentially 'rescue collecting' in the face of inevitable destruction by machinery. All involved were alert to the fact that rich but finite palaeontological and geological information was being lost before it could be recorded and understood. Ongoing quarrying meant that new exposures were being regularly created and destroyed, often on a daily basis.

The Database Group of the Geological Society of Norfolk was established by A.J. Read in 1991 to log temporary exposures in the county, for the purpose of 'rescue geology'. In March 1994 the Group began logging temporary sections in the Manor Farm Pit, as many as possible in the time available. Most sections were intensively sampled for sediments and some for micro-palaeontological analyses, as well as for faunal remains and plant macros. V.J. Banks conducted a levelling survey using a total station kindly lent by A.F. Howland Associates Ltd, to fix the positions of sections, stratigraphic marker horizons and salient 'landmarks' on the site thus enabling them to be tied to Ordnance Datum. The main bone-bearing strata were identified; key exposures were excavated and recorded in May and June 1994, the results of which form the subject of this report. Members of the Geological Society of Norfolk visited the site at a field meeting in May that year.

At the same time, Prof. J. Rose and C. Green (Royal Holloway, University of London; hereafter RHUL) studied available sections on a number of visits and led a team of postgraduate students at the site. The RHUL research included OSL dating (R. Bailey and N. Perkins), molluscs (S.B. Dixon), pollen and plant macros (F.E. Mayle), fluvial sediments (P. Pieruccini) and coleoptera (A.P. Walkling). C.R. Stevenson (Norfolk College of Arts and Technology, Kings Lynn) conducted preliminary work on the bryophytes. Initial results from pollen, beetle and mollusc analyses indicated that Manor Farm Pit yielded the first essentially continuous sequence of fossiliferous deposits from Britain spanning the entire Ipswichian interglacial and the transition into the Devensian glacial periods (Mayle *et al.*, 1996). Information about the bone bed was communicated by the present author and J. Lightwing to the conference 'Vertebrate Remains in the Quaternary' at Coventry University, UK (September 1995). The results of fossil collecting work in 1994 were summarised by J. Lightwing in an undated document 'Shropham Faunal List and Location of Specimens', now archived at the British Museum (Natural History). It gives an account of the species collected from undoubted Ipswichian contexts by named collectors, and refers them to localities defined by the Database Group. Major collections of Shropham material are now housed at the British Museum (Natural History), the Dick Mol Collection[1], the Harrison Institute[2] and the National Museum of Wales.

[1] https://en.wikipedia.org/wiki/Dick_Mol [accessed August 2015]
[2] The Harrison Institute - http://www.harrison-institute.org/collections/FossilMammal_collections.html [accessed August 2015]

THE STRATIGRAPHY OF MANOR FARM PIT

A simplified composite lithostratigraphic sequence of seven units (Table 1) was compiled by the author and members of the Database Group from exposures of the bone bed and associated strata visible in the western wall and adjacent quarry floor in May 1994. Other units were recorded at the time but are not presented here, being not directly related to the bone bed excavations.

Stratigraphic orientation within the chaotic conditions of the working quarry was facilitated by the following observations made by members of the Database Group:

- Unit Sh-1 formed a marker horizon near the base of the sequence. It was horizontally bedded in the centre of the pit and overlain there by an apparently conformable sequence of Units Sh-2 and Sh-3. Its upper surface was dipping significantly at the western side of the pit, south-eastwards in the direction of the Thet valley; it was here unconformably overlain by Unit Sh-4.
- A bone bed of vertebrate fossils in a good state of preservation occurred at the interface between Units Sh-1 and Sh-4 (Fig. 4).
- The geology of the central and southern parts of the pit above Sh-1 was complex, with evidence of much fluvial and slump reworking of apparently similar sands, silts and gravel units visible in the various quarry terraces, trenches and graded areas. Units Sh-2 and Sh-3 were thickest in the central and south-eastern areas of the pit (towards the middle of the Thet valley).
- *Hippopotamus amphibius* fossils occurred abundantly in Units Sh-3 and Sh-4, a species indicative of the Ipswichian interglacial (Stuart 1976; 1982, p. 53; Schreve 2001, 2009). This indication was supported by the presence of fruits of the thermophilous plant *Trapan natans* and fossils of the European pond turtle *Emys orbicularis*.

Table 1. Lithostratigraphic sequence in western quarry area, May 1994.

Units	Geology and palaeontology
Sh-7	Orange to pale yellow, massively-bedded sands, grading downwards into light-grey sands and silty clays with convoluted bedding.
Sh-6	Planar-bedded, laminated grey silts with increasingly organic-rich laminations towards the base; erosive contact with underlying unit.
Sh-5	Matrix and clast-supported +/- horizontally-bedded, predominantly pale yellow, flint-rich gravels with rounded to subangular clasts, and cobbles showing imbrication indicating palaeocurrent flow south-eastwards; interbedded with well-sorted, grey sand lenses and some organic-rich silt layers; some re-worked blocks of cross-bedded, organic-rich silt and sand. Identified as a braided river deposit. Marked erosional contact with underlying unit.
Sh-4	Dark brown diamicton, comprising abundant angular and subangular black flint clasts in 1-3 cm range in a matrix of sandy silt and brown organic mud containing occasional molluscan shells and plant remains; interbedded with subfacies horizons of similarly flint-rich, grey sand. A vertebrate macrofossil bone bed is present at the base of this unit, with species represented including steppe bison *priscus*, straight-tusked elephant *Palaeoloxodon antiquus* and hippopotamus *amphibius*. Interpreted as a mass movement deposit. Marked erosional contact with underlying unit.
Sh-3	Organic-rich, brown, fossiliferous, detrital silts and muds interbedded with sand layers containing molluscan shells; bedded sub-horizontally in the centre of the pit. Plant macrofossils including hazel *Corylus avellana* and water chestnut *Trapa natans*; invertebrate macrofossils including *Limnaea, Unio, Bithynia, Planorbis*; vertebrate macrofossils including European pond turtle *Emys orbicularis* and beaver *Castor fiber*. Interpreted as a fluviatile deposit.
Sh-2	Fine to coarse fluviatile grey sands, fossiliferous, with cross bedded units; slightly erosive contact with underlying unit. Identified as a fluviatile deposit.
Sh-1	Laminated, calcareous silty clay, pale olive green, massively bedded, containing abundant molluscan fossils. Identified as a biogenic lacustrine *Chara* marl. Thickest (over 2 m) in the eastern part of the quarry. Dipping gently in a south-easterly direction.

- Coarse yellow gravels (Unit Sh-5) formed a marker horizon in the upper part of the sequence. They had an erosional relationship with underlying units. They are interpreted as cold-phase, braided river deposits of Devensian age that underlie the present floodplain of the Thet valley and Terrace 1 as marked on the geological map (British Geological Survey, 1989). Occasional vertebrate specimens in a poor state of preservation were recovered from this and various overlying units.
- Chalk was said to have been encountered by quarrying at the northern end of the pit in 1993 (A.J. Read, pers. comm.), although these beds were inaccessible in 1994 due to flooding.
- The slopes of the valley side immediately to the west of Manor Farm Pit consist of till of the Lowestoft Formation (British Geological Survey, *ibid*).
- Quarrying on the western side of the pit in July 1994 revealed a sequence of sands and gravels underlying the Ipswichian deposits. They were assumed to be deposits of Wolstonian age.

A separate stratigraphy compiled by the RHUL team is given in Appendix 2.

THE BONE BED AT MANOR FARM PIT

Location of rescue excavations

The author conducted a series of controlled excavations in the western wall (Area Y) and adjacent graded floor (Area U) of the quarry in April, May and June 1994. These areas were chosen for investigation because the bone bed was accessible in both vertical and horizontal dimensions, and because it was stratigraphically constrained by two marker horizons, Units Sh-1 and Sh-4. The location of the excavations is given in Table 2 and Figure 5.

Fig. 4. The diamicton Unit Sh-4 unconformably overlying *Chara* marl Unit Sh-1, with a scapula and astragalus of *Bison priscus* as clear evidence of the bone layer at the interface. Gravels, possibly Unit Sh-5, cap the sequence. Seen in Area C on the floor of the quarry, May 1994.

Table 2. Location of excavation sites

Area Y – Western quarry wall, facing east	
Section Z	3.5 m long x 1.5 m high, oriented east-west, with a datum point at its western end. It was removed by quarrying in June 1994.
Section Y	7.5m long x 1.5 m high, oriented N-S, sharing a datum point at its northern end with Section Z. It was removed by quarrying in July 1994.
Section X	3.5 long x 1 m high, oriented east-west, 4.65 m due north of datum. Height relative to datum was not measured. It was removed by quarrying in June 1994.
Site X	An area of approx 10 m^2 on graded floor of quarry close to Section X, c.10 m north of datum. Height relative to datum was not measured, but was approximately the same level. It was removed by a quarrying in May 1994.
Area U – Graded quarry floor	
Site T	An area of approx 10 m^2, 20 m from datum point on a bearing 138° N. Height relative to datum was not measured. It was removed by quarrying in June 1994.
Site V	An area of approx 4 m^2, 16 m from datum point on a bearing 165° N, and at a height of 1.7 m below than datum level. It was removed by quarrying in June 1994.

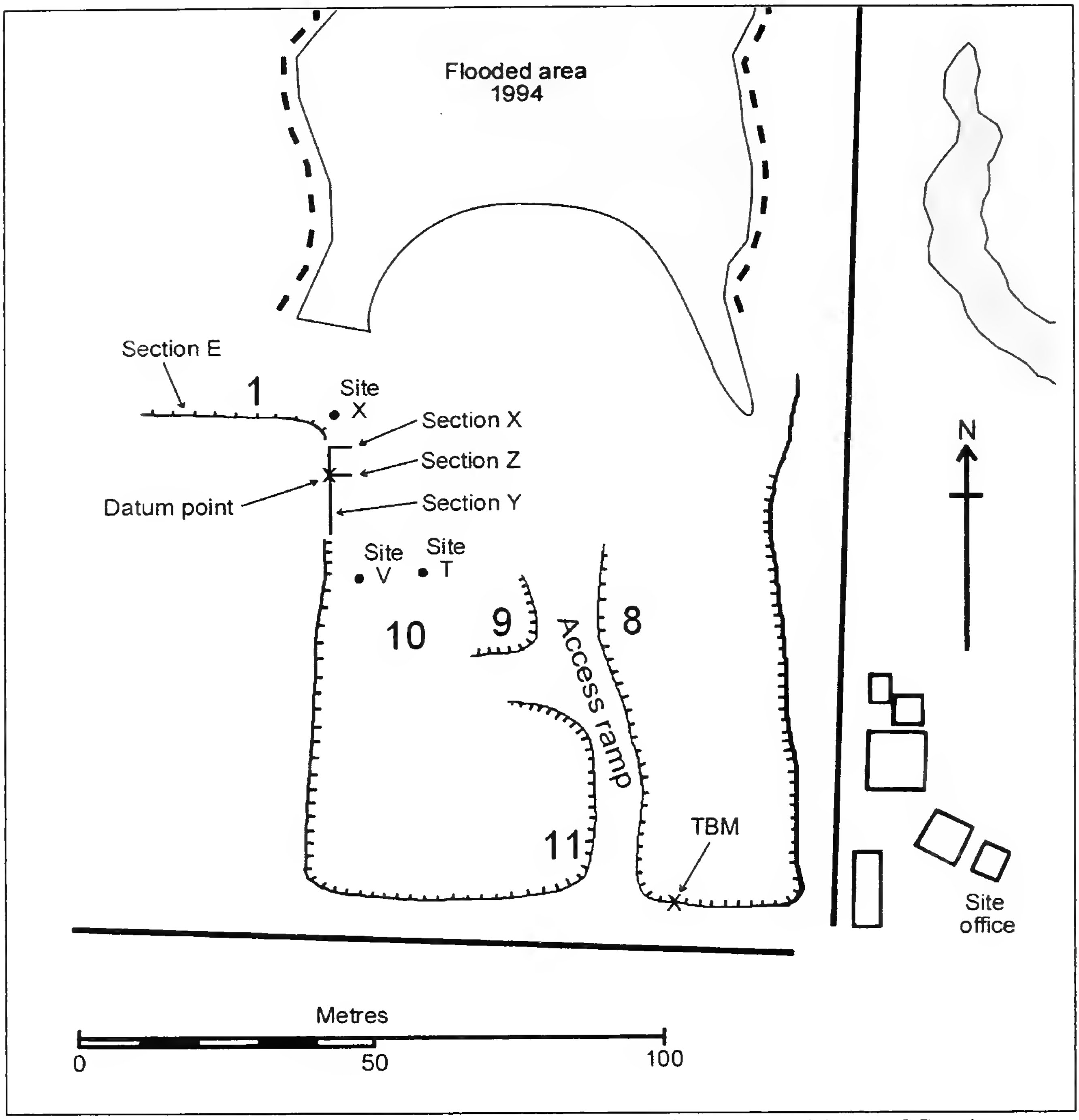

Fig. 5. Plan of Manor Farm Pit, May-July 1994, showing the positions of Sections and Sites (lettered) and RHUL Profile sites (numbered). TBM indicates position of temporary benchmark surveyed by V. Banks.

Excavation methodology

The excavation took place discontinuously over several weeks, as other work commitments permitted. It was carried out using basic archaeological techniques by the author and helpers (see Acknowledgements). Taphonomic information was collected following the technical guidance of Rogers (1994). Vertebrate specimens were identified using Schmid (1972), Walker (1985) and Hillson (1992).

Procedures were as follows:

- Sections and areas were exposed by hand and cleaned with a trowel.
- A datum marker post was installed.
- Measurements were taken in two dimensions from a horizontal tape stretched on a compass bearing from datum.
- Locations of finds were recorded in two dimensions by plotting onto squared paper: each find was numbered: the result was a composite diagram showing either the vertical or horizontal distribution of finds.
- Photographs were taken.
- Representative sediment samples were taken from Sections Y, Z and Area U.
- Orientation (azimuth and dip) were recorded for specimens having a significant long axis in Sections Y and Z.
- Fossil specimens and lithological samples were assigned identity numbers, either THW collection numbers or sedimentary context numbers.

Limitations of method

- Sediment was not sieved for small vertebrate remains.
- Surveying equipment was not used while excavations proceeded, so relative heights and horizontal co-ordinates of excavated sites and sections should be regarded as approximate. A datum post was established for geometrical purposes: it is estimated to have been located at approximately 19.7 m OD (Fig. 6). The Ordnance Survey 1:25,000 Explorer series map indicates the natural ground surface at Manor Farm Pit lies at approximately 24 m OD. Allowing for surface stripping of topsoil to a depth of 30 cm by the quarry company, datum is estimated to have been located at a depth of 4.0 m below this surface, by reference to the height of Section Y. At the time of writing it has not been possible to link datum to the temporary bench mark surveyed by V.J. Banks and indicated in Figure 5.

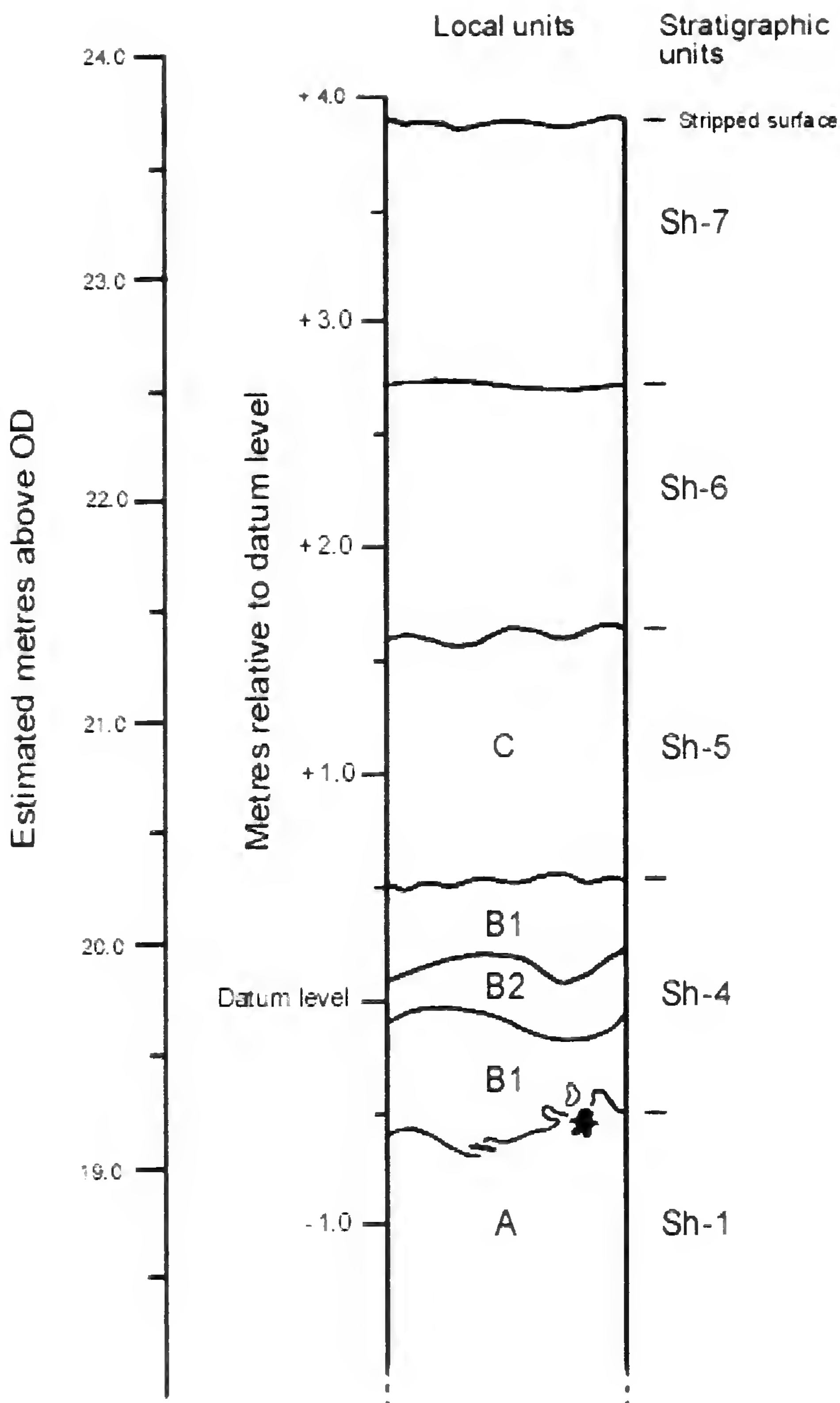

Fig. 6. Section Y, May 1994, concordance between stratigraphic units as defined in Table 1, datum level and estimated height above OD.

Excavation log

Local information was recorded for Area Y and Area U, supported by exposure diagrams (Figs 7-10) and photographs (Figs 11-15) for Sections Y and Z and Site T. Local sedimentary units are lettered A, B and C. Section X is not figured here, as it did not yield vertebrate specimens. A graphic record was not made of Site X.

1. Area Y - Western quarry wall – Sections X, Y and Z, and Site X

Sedimentology of local units

Unit A Calcareous silty clay

- A^1 Massively-bedded, greyish-green marl, with occasional molluscan remains. Frequent bones in uppermost 10 cm and/or partly in overlying Unit B. Sample Z#23.
- A^2 Olive grey altered horizon at top of A^1, laterally discontinuous, in places mixed into A^1. Sample Z#22.

Contact between Units A and B:

Erosional; dipping south-eastwards a c.10°; boundary contorted, showing flame and load cast structures.

Unit B Diamicton

- B^1 Dark brownish-grey, muddy, massively bedded diamicton; matrix of sand and brown organic mud, with abundant angular and sub-angular black flints (1-3 cm range), and occasional shells and plant remains. Frequent bones, especially in lowest 20 cm. Average dip of sub-unit south - eastwards at between 10° and 20°. Sample Z#1.
- B^2 Light grey, sandy, massively bedded diamicton; matrix of sand with abundant flints; low organic mud content compared with B^1. Occasional bones. Dip as B^1.

Contact between Units B and C:

Erosional; unconformable; dipping gently south-eastwards at c.5°.

Unit C Sands and gravels

- C^1 Yellow sand, with basal lag of pale brown, plastic clay draped over eroded upper surface of Unit B. Sample Z#2.
- C^2 Coarse-grained, yellow, gravelly sand, containing small yellowish sub-angular and sub-rounded flint clasts and frequent cobbles.
- C^3 Contorted diamicton: grey, silty sand with yellow sand stringers, highly deformed bedding, channelled into C^2 and B, black angular and sub-angular flints, occasional carbonised plant remains and marl clasts (derived from Unit A) and weathered bones.

Systematic palaeontology

Plantes

Undetermined

Section Y, Stratum A/B: Y#10 wood frags; Y#11 wood frag, large water-worn; Y#11. Section Y, Stratum B^1: Y#9 wood frags. Section Z, Unit B^1: Zwood#1 wood frags; Zwood#2 wood frags; Zwood#3 wood frags.

Angiospermae
Undetermined
Section Y, Stratum A: Y#20 seeds.
Betulaceae
Corylus avellana L.
Section Z, Stratum B^1: Zwood#4 nut frags.
Reptilia
Emydidae
Emys orbicularis L.
Section Y, Unit A: Y#17 carapace frags.
Site X, Unit A/B: X8 carapace frag.
Mammalia
Undetermined
Section Y, Unit A: Y#18 bone frags.
Section Y, Unit A/B: Y#2 rib frag; Y#3 pelvis frag; Z#12 bone frags.
Section Y, Unit B^1: Y#19 rib frag.
Section Z, Unit C^2: Z#7 bone frag.
Section Z, Unit C^3: Z#5 bone frag.
Site X, Unit A/B: X#4 bone frag.
Artiodactyla
Artiodactyl undet.
Section Z, Unit A/B: Z#6, rib, prox frag.
Bovidae
Bovid undet. (*Bos primigenius* Bojanus or *Bison priscus* Bojanus)
Section Y, Unit A/B: Y#1 vertebra; Y#12 metatarsal cannon bone; Y#13 vertebra, [3rd] cervical; Y#14 +15 vertebra, in two pieces.
Section Y, Unit B^1: Y#8 vertebra frag.
Section Y, Unit B^2: Y#5 rib frag.
Section Z, Unit A/B: Z#10 tooth, incisor; Z#11 tooth, molar.
Section Z, Unit A/B: Z#2 vertebra, thoracic; Z#3 humerus, distal frag; Z#9 rib, prox frag.
Section Z, Unit B^1: Z#1 humerus, distal frag; Z#8 humerus frags.
Site X, Unit A: HW94.15 rib frag.
Site X, Unit A/B: X#2 rib, frag; X#3 phalanx hoof; X#5 astragalus; HW94.19 vertebra, thoracic; HW94.21 vertebra, last thoracic; HW94.24 rib.
Cervidae
Small cervid undet. [*Capreolus capreolus* L. or *Dama dama* L.]
Section Y, Unit A/B: Y#6 rib; Y#16 rib.
Section Y, Unit B^1: Y#7 humerus distal frag.
Section Y, Unit B^2: Y#4 rib frag.
Section Z, Unit B^1: Z#4 mandible frag, with teeth.
Site X, Unit A/B: HW94.27 rib frag.
Hippopotamidae
Hippopotamus amphibius L
Site X, Unit A/B: X#1 atlas vertebra; X#6 tooth, canine; X#7 tooth, incisor; X#9 tooth, canine; HW94.28 tooth, canine, pyritised.

2. **Area U - Graded quarry floor – Site T**

Sedimentology of local units

Unit A Fossiliferous marls and sands

A^1 Pale brown, calcareous, silty clay, rich in plant remains, including nuts of *Corylus avellana*. Surface dipping towards south-east at shallow angle approximately 5°.
Grading upwards into overlying unit.

A^2 Grey, shell-rich sand.

Contact between Units A and B:
Unconformity.

Unit B Diamicton

B^1 Dark brownish-grey, muddy diamicton, as exposed in Sections Y and Z. Frequent bones in basal stratum. Average dip of Unit towards south-east at between 0° and 10°.

B^2 White sand occurring as lenses in Unit B^1.

Systematic palaeontology

Mammalia
Undetermined
Stratum A/B: T#2 bone frags; T#3 rib, frag.
Perissodactyla
Rhinocerotidae
Rhinocerotid undet. (cf *Stephanorhinus hemitoechus* Falc.)
Stratum A/B: T#4 rib; T#8 rib; T#9 rib; T#10 rib.
Artiodactyla
Bovidae
Bovid undet. (*Bos primigenius* Bojanus or *Bison priscus* Bojanus)
Stratum A/B: T#1 metatarsal cannon bone, prox frag; T#5 humerus, distal frag with tooth marks and crenulated end.

Cervidae
Small cervid undet. [*Capreolus capreolus* L. or *Dama dama* L.]
Stratum A/B: T#7 metacarpal cannon bone.
Hippopotamidae
Hippopotamus amphibius L.
Stratum A/B: T#6 scapula

3. **Area U - Graded quarry floor – Site V**

Sedimentology of local units

Unit A Silty clay

Unit A^1 Massively bedded, greyish-green, calcareous silty clay (*Chara* marl), with occasional molluscan remains. Surface dipping towards south-east at approximately 20°. Becoming sandier upwards.

Unit A^2 Grey, shell-rich sand.

Contact between Units A and B:

Unconformity.

Unit B Diamicton

B Dark brownish-grey, muddy diamicton, as Unit B^1 exposed at Site T.

Systematic palaeontology

Plantes

Undetermined

Unit A/B: V#1: wood, frags.

Mammalia

Perissodactyla

Rhinocerotidae

Stephanorhinus hemitoechus Kretzoi.

Unit A/B: V#4: mandible.

Discussion and Analysis

Areas Y and U were chosen to investigate; a) a vertical section of the bone bed in the western area of the pit, and; b) the horizontal distribution of vertebrate remains in the bone bed exposed on the graded floor of the quarry.

Area Y

The diagrams for Sections X, Y and Z show the bone bed as displayed at the interface between local units A (marl) and B (diamicton); these are correlated with Units Sh-1 and Sh-4 respectively. The mean dip of the beds is south-eastwards at a 10° angle, and the interface is contorted by flame and load cast structures with cuspate microfold axes oriented towards the south-east (Fig. 13). Such structures are formed due to density inversion, when gravity loading by a denser unit acts on a less-dense underlying unit that is unstable due to higher porosity and lower competence (Collinson & Thompson,

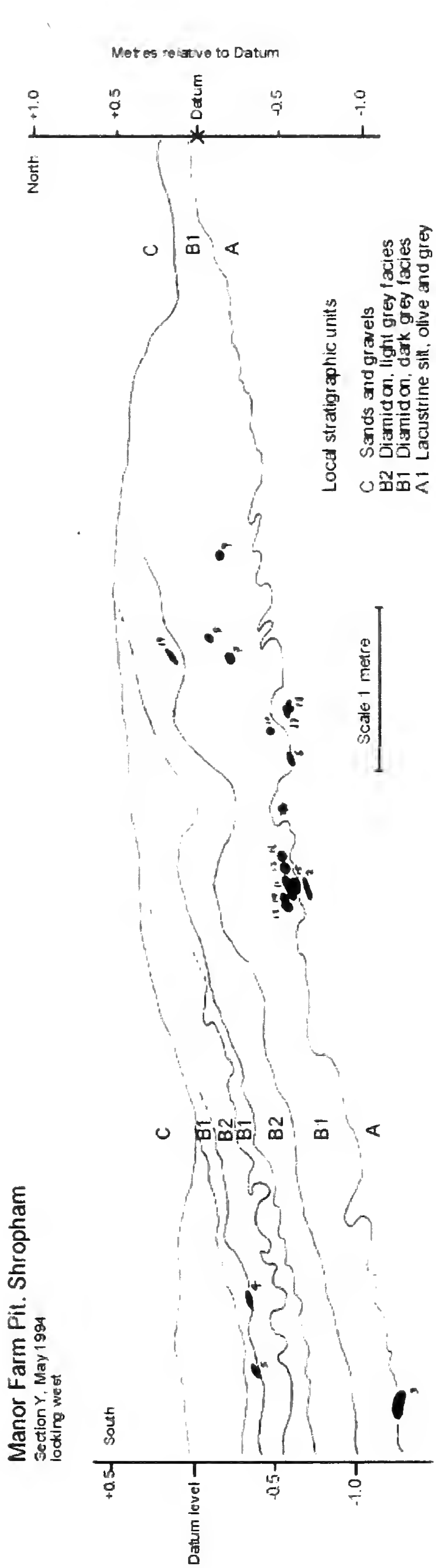

Fig. 7. Section Y, showing stratigraphy of local units A to C with location of selected specimens indicated.

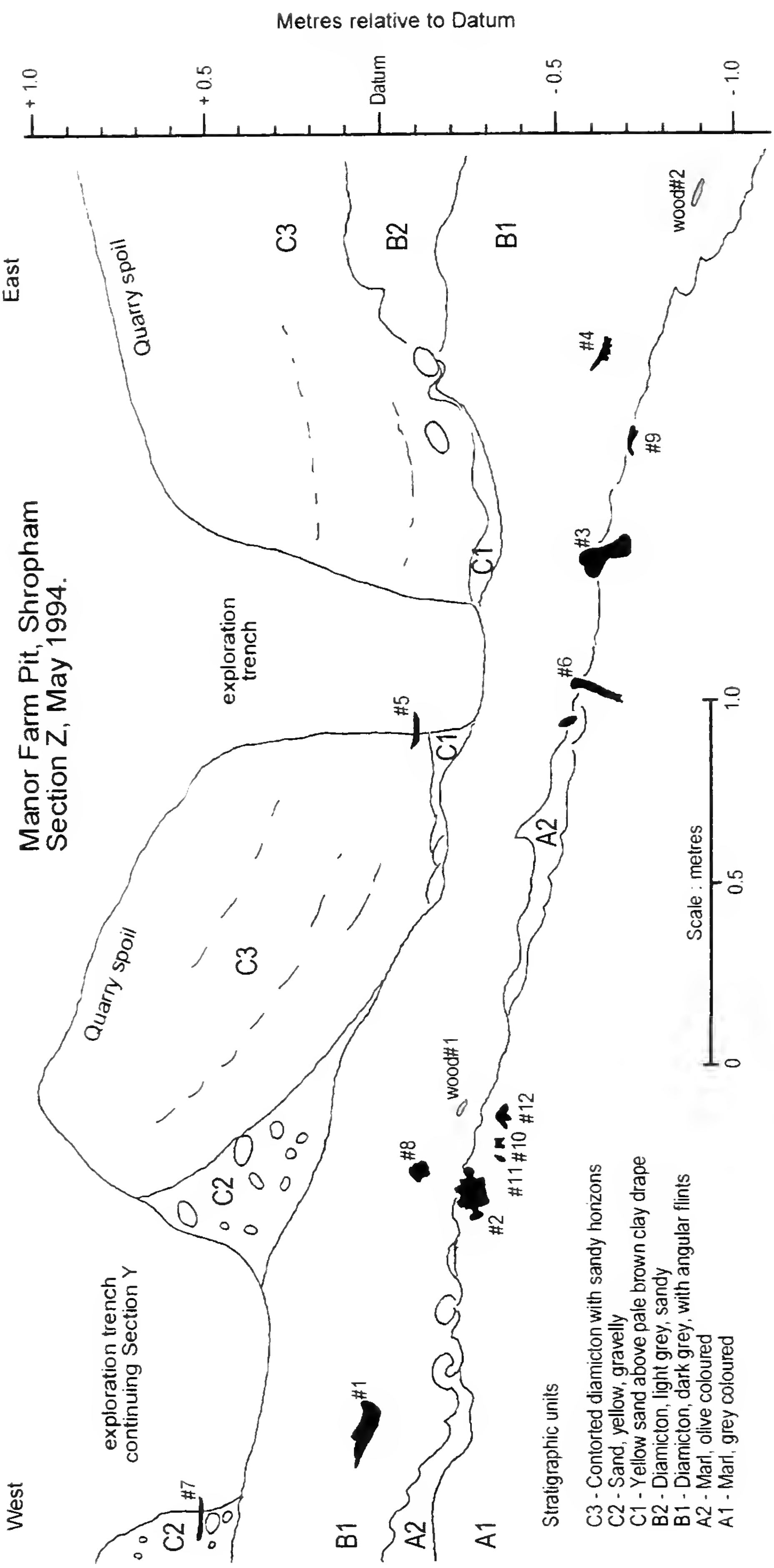

Fig. 8. Section Z, showing stratigraphy of local units A to C with location of selected specimens.

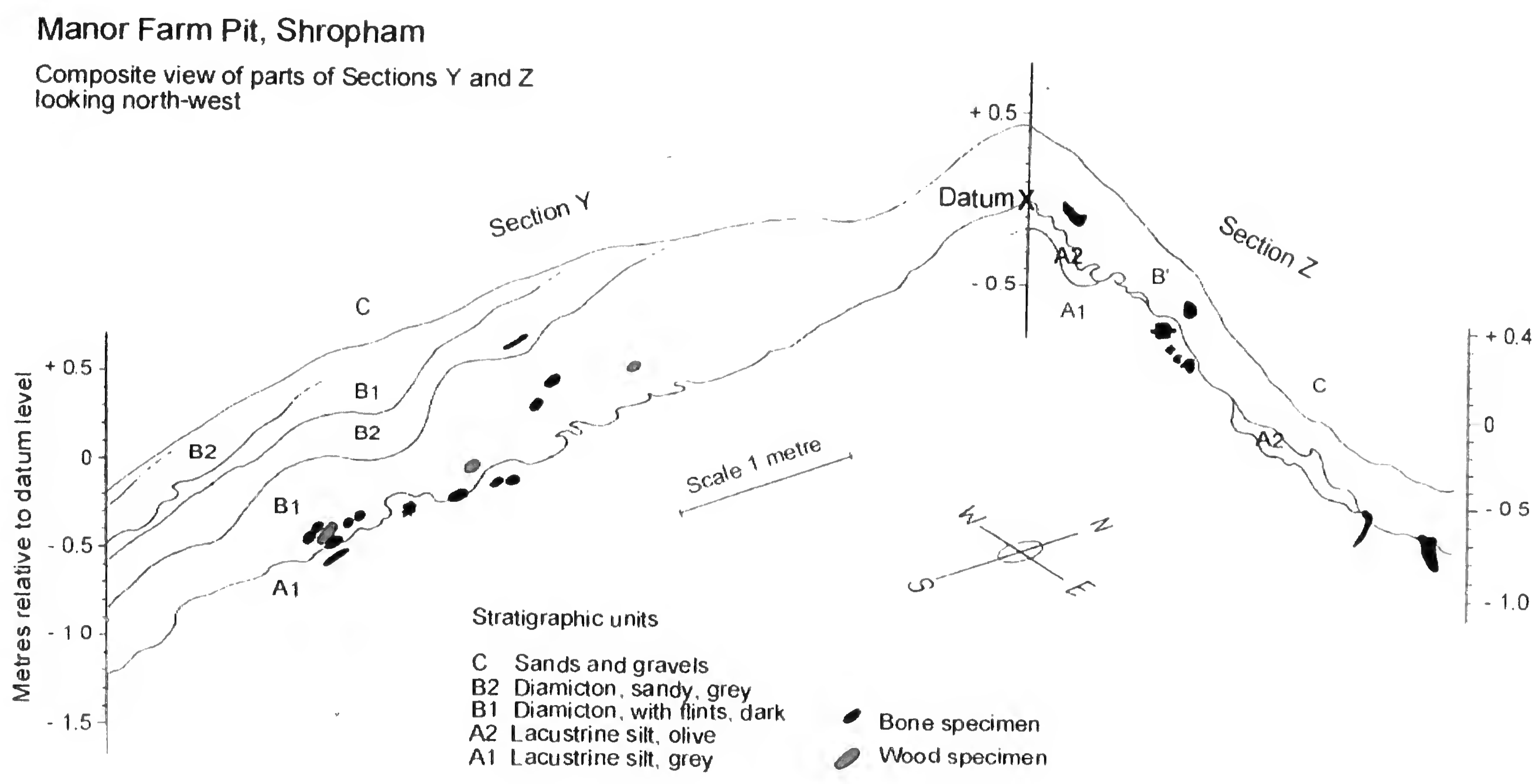

Fig. 9. Summary composite view of parts of sections Y and Z, showing stratigraphy of local units A to C with distribution of specimens.

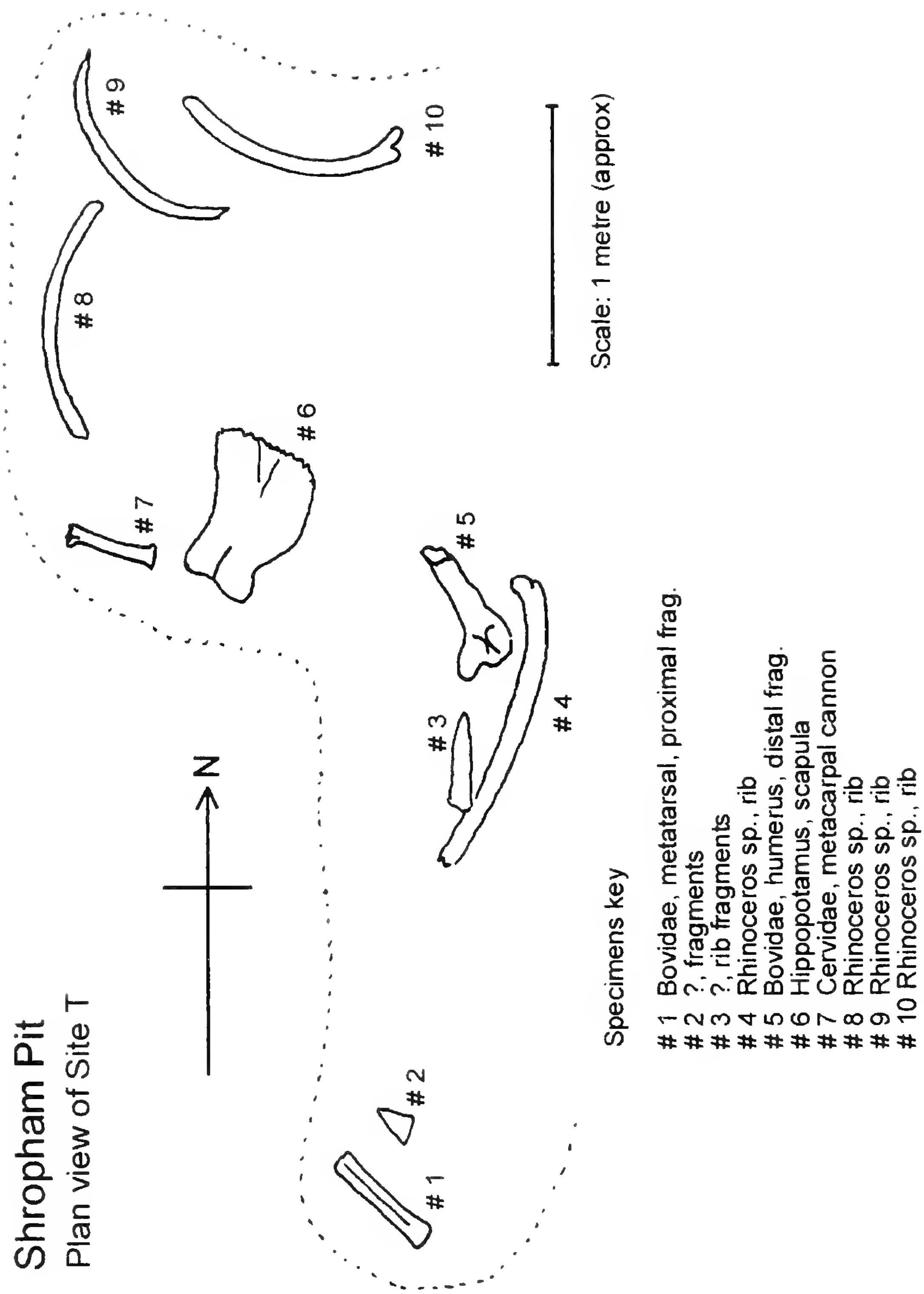

Fig.10. Plan view of Site T. Specimens not drawn to scale.

1989, p.147). The interface therefore records a vector of gravity loading from the north-west. Some of the bones are partially embedded in the uppermost layers of unit A, which is evidence of dynamic emplacement. The quantity of bones in the basal horizon of unit B is greater than higher up in the unit (Fig. 9). The bedding of unit A is highly contorted (Fig. 13). Unit B is composed of alternating dark and light subfacies (B^1 and B^2) (Fig. 14), and the sediment of the lighter facies is distinguished by a greatly reduced detrital muddy fraction. The interfaces between them are undulating and convoluted, notably higher in the unit at the southern end of the section (Fig. 7). This convolution is interpreted as evidence of plastic flow during deposition.

Units A and B are unconformably overlain and truncated by the sands and gravels of unit C, which is correlated with Unit Sh-5 (Fig. 8). The boundary presents an angular unconformity. A basal lag of pale brown, highly plastic clay (C^1) is preserved in pockets on the upper surface of Unit B (this is likely to be a reworked remnant of the 'sticky khaki clay' of Anglian age recorded in BGS borehole TL99SE15 mentioned above). It is unclear how it relates to unit C^2; the two may belong together as one sub-unit. The poorly-sorted, sandy diamicton of unit C^3 is clearly channelled into C^2 and unit B; it shows evidence of rapid deposition, and may represent a slump debrite. Forty-two bones were recovered from units A and B, and the majority were found resting on, or slightly embedded in, the uppermost layers of unit A. Specimens are fresh-looking condition with a distinctive, reddish-chestnut brown colour and a matt to silky lustre, suggesting good preservation. Some specimens are fragmentary but most are intact. Two undetermined, fragmentary bones were recovered from unit C in Section Z.

Area U

The bone bed was displayed at the boundary between local units A (comprising A^1 lacustrine marl overlain by A^2 shelly sand) and B (diamicton). A^1 and A^2 are correlated with Units Sh-1 and Sh-2 respectively, and B with Sh-4. The contact between units A and B was dipping gently south-eastwards.

Fig. 11. Section Y, excavation of the bone bed with assistance from Ben Platts-Mills, with indication of stratigraphic Units. Scale: 1 metre.

Fig. 12. Section Z looking NE, excavated with assistance from Tracey Mawby, showing bovid vertebra Z#2, undetermined rib fragment Z#6 and bovid humerus Z#3 at boundary between units A and B. Scale: 1.5 m.

Fig. 13. Section Y, middle, 10th June 1994. Showing contorted bedding of unit A and interface between A and B. Specimens Y#1 (vertebra) and Y#2 (broken rib, left of centre) are *in situ*. The irregular vertical, pale 'veins' are interpreted as water escape structures.

Fig. 14. Section Y, southern end, showing alternating light and dark facies of unit B, and specimen Y#4 (rib) *in situ* near trowel. Note: the various dark vertical scorings are trowel marks.

Fig. 15. Section Y. middle. 10th June 1994. Showing cluster of specimens. comprising water-worn wood fragment (#11) in close association with bovid metatarsal (#12) and cervid rib (#16). Other associated specimens (#13. #14 and #15) were removed earlier.

Eleven vertebrate specimens were recovered from Area U. found resting on. or slightly embedded in. the uppermost layers of unit A. Their condition of preservation is similar to specimens from area Area Y.

Identification of specimens

The taxonomic identification of specimens is summarised in Table 3: further study may allow some undetermined taxa to be identified. The preponderance of large bovid (either *Bos primigenius* or *Bison priscus*) specimens is evident (43%). and is in keeping with observed preponderance recorded elsewhere in the quarry by other workers. Many of the undetermined artiodactyl bones are likely to be bovid: post-cranial bones of *Bos primigenius* and *Bison priscus* are difficult to resolve to species level (Stuart. 1982: Gee. 1993).

Table 3. Breakdown of specimens by taxon for Areas Y and U.

Kingdom / Class	**Order / Family**	**Species**	**No. specimens**	**% mammal finds**
Plantes	Undetermined		8	
	Corylaceae	*C. avellana*	1	
[Angiospermae]			1	
Animalia				
Reptilia	Testudines			
	Emydidae	*E. orbicularis*	2	
Mammalia	Undetermined		10	19.61
	Artiodactyla		1	1.96
	Bovidae	*B. primigenius* or *B. priscus*	22	43.14
	Cervidae	*C. capreolus* or *D. dama*	7	13.73
	Hippopotamidae			
		H. amphibius	6	11.76
	Perissodactyla			
	Rhinocerotidae		4	7.84
		S. hemitoechus	1	1.96
				100 %

Faunal assemblage

The faunal assemblage represented in the bone bed is interpreted as an interglacial one, as evidenced by the occurrence of thermophile species hazel *Corylus avellana*, European pond turtle *Emys orbicularis* and hippopotamus *Hippopotamus amphibius*. On the basis of the occurrence of *H. amphibius* it is correlated with the Ipswichian interglacial (Stuart, *ibid*; Schreve, 2009). Appendix 1 shows a composite faunal list for Manor Farm Pit.

The presence of a range of local environments may be inferred from the species list, including aquatic dwellers (*E. orbicularis, H. amphibius*), woodland browsers (*C. capreolus* or *D. dama*) and browsers in more open habitats (*S. hemitoechus* (Fortelius *et al*, 1993)); the habitat preferences for *B. primigenius* is thought to have been floodplain and marshy woodland (Van Vuure, 2002), and for *B. priscus* predominantly grassland areas (Guthrie, 1990).

Table 4. Azimuth orientation of skeletal elements.

Specimen	Orientation °N	Specimen	Orientation °N
Y#1	155 / 335	Z#7	90 / 270
Y#2	170 / 350	Z#8	20 / 200
Y#3	65 / 245	T#1	135 / 315
Y#4	45 / 225	T#2	n / a
Y#5	65 / 245	T#3	180 / 360
Y#6	160 / 340	T#4	15 / 195
Y#7	90 / 270	T#5	154 / 334
Z#1	65 / 245	T#6	22 / 202
Z#2	140 / 320	T#7	106 / 286
Z#3	170 / 350	T#8	4 / 184
Z#5	40 / 220	T#9	140 / 320
Z#6	130 / 310	T#10	103 / 283

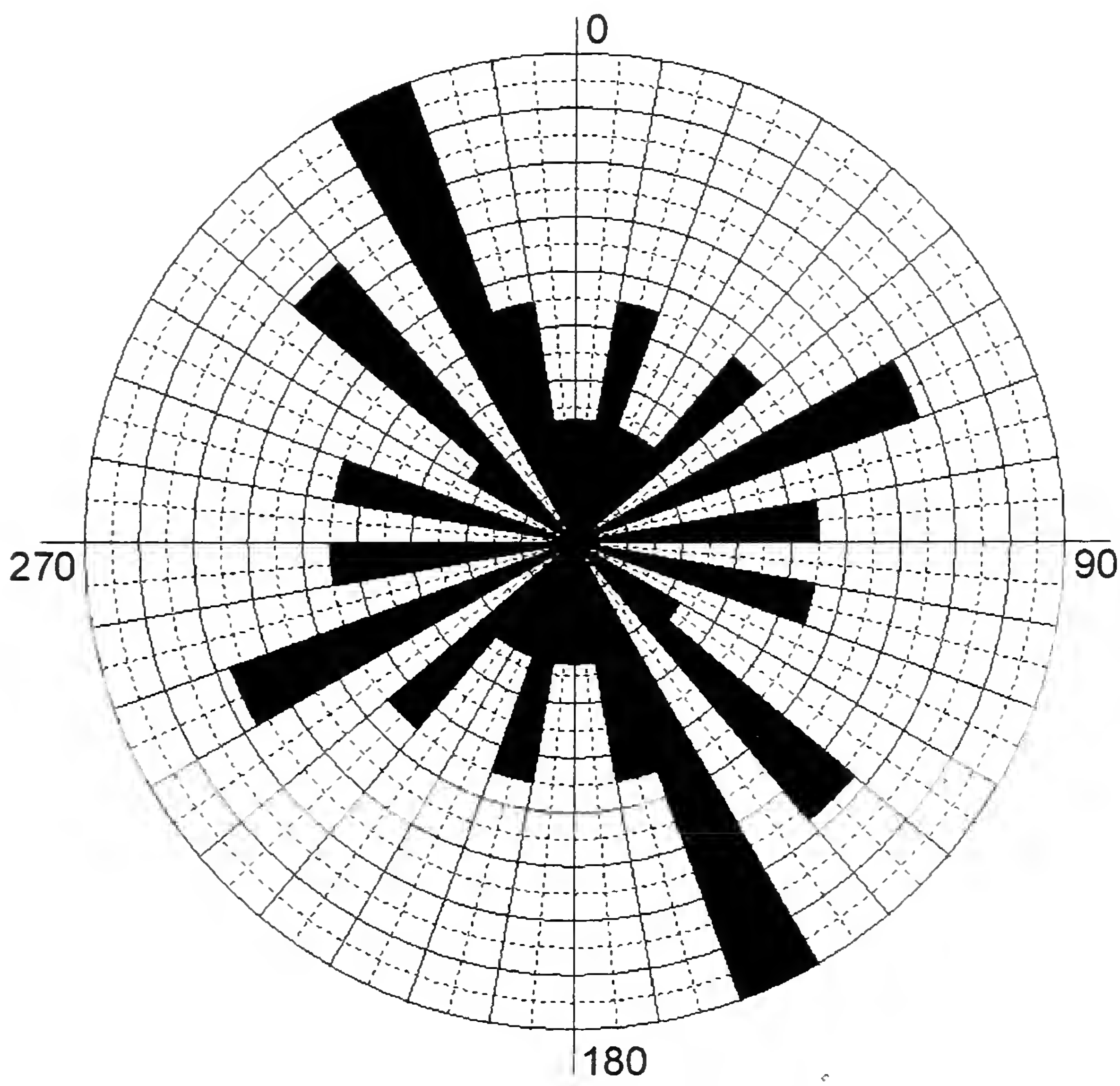

Fig. 16. Mirror-image rose diagram showing azimuth orientations of 15 skeletal elements in Sections Y and Z and 9 elements in Site T. 0° corresponds with compass North.

Taphonomic detail – azimuth orientation of skeletal elements

Figure 10 shows a plan view of 10 skeletal elements in Site T. Azimuth orientation data for 24 of the most elongated bones from Site T and Sections Y and Z may be combined (Table 4) to yield a composite indication of patterning in the bone bed. and the results plotted on a mirror-image rose diagram (Fig. 16).

Taphonomic detail – systematic breakdown of skeletal elements

Table 5 summarises the total frequencies of specimens by skeletal element. and gives an indication of the various fluvial dispersal potentials of these elements according to Voorhies Group status. Voorhies Groups are correlated with the structural densities of bones. and indicate the probability that disarticulated bones of a skeleton would be sorted by hydrodynamic processes into groups of readily and non-readily moved elements (Lyman. 1994. p.172). Group I indicates those most easily winnowed by running water. and Group IV those least easily winnowed.

Analysis shows that a wide range of size types of skeletal elements are present. ranging from small. such as bovid phalanges and chelonian scutum plates. to large. notably an intact rhinocerotid mandible. "*The proportions of different Voorhies Groups in fossil assemblages should provide evidence for the proximity of fossils to the original thanatocoenose and the habitats of the living animals*" (Behrensmeyer. 1975. quoted in Lyman. *ibid*). Specimens with both high and low dispersal potentials in running water are present in the bone bed (Table 6). suggesting that winnowing of skeletal elements by water is unlikely to have been a significant factor in the primary accumulation of these specimens. Examples of smaller. more easily scavenged elements such as phalanges and metatarsals are present. suggesting that the assemblage did not undergo significant scavenging before burial. The observed accumulation of skeletal elements thus broadly reflects the composition of the original death assemblage: subsequent dispersal has not acted significantly to modify its composition.

Table 5. Frequencies of skeletal elements of 38 vertebrate specimens from Areas Y and U, with indications of fluvial dispersal potential (Voorhies Group status). (* indicates significant incompleteness of element.)

	Mammal Indet	Artiodactyl indet	Bovid indet (B.primegius or B.priscus)	Cervid indet (D.dama or C.capreolus)	H. amphibius	S.hemitoechus and Rhiocerotid indet.	E. orbicularis	Voorhies Group
Mandible				1*		1		II & III
Tooth			2		4			n/a
Vertebra			7		1			I
Pelvis	1*							II
Rib	3	1	5	4		4		I
Scapula					1			I & II
Humerus			4	1				II
Astragalus			1					n/a
Metacarpal				1				II
Metatarsal			2					II
Phalanges			1					I & II
Scutum							2	n/a
Indet frag	6							n/a

Table 6. Breakdown of total skeletal elements of 38 vertebrate specimens from Areas Y and U according to fluvial transport potential (Voorhies Group status).

Dispersal potential Groups	Total skeletal elements
I	25
II	9
III	
I & II transitional	2
II & III transitional	2
Total specimens	38

Plant specimens

A quantity of plant specimens were recovered during the excavation. Only nut fragments of *Corylus avellana* could be identified to species level. The remainder were retained, pending more precise identification. These included a large, water-rounded wood fragment (Y#11; Fig. 15), likely to have been well waterlogged at the time of burial and suggesting fluvial transport to its initial site of deposition.

INTERPRETATION

The bone bed

A bone bed may be defined as a *'relative concentration of vertebrate hardparts preserved in a localized area or stratigraphically limited sedimentary unit (e.g., a bed, horizon, stratum) and derived from more than one individual'* (Rogers & Kidwell, 2007). Such concentrations may have a complex taphonomic history, making them a challenge to interpret. What follows is an attempt to reconstruct the taphonomic history of the Manor Farm Pit bone bed.

Primary depositional context

The geology of sections Y and Z suggests that the bones were found in secondary depositional context. Their primary context was evidently a deposit that is dated, on the basis of the faunal assemblage, to the thermal optimum of the Ipswichian interglacial (MIS 5e). Taphonomic information derived from this excavation and others in the bone bed supplied by other workers (J. Clayden, J. Lightwing, pers. comm.) sheds light on environmental conditions in these deposits.

State of preservation

- Many bones were found in fresh-looking (unrolled and unweathered) condition, suggesting rapid burial at the site of primary deposition, and minimal transport distances to their secondary context.
- Many bones had signs of predator damage. There was evidence for gnawing, including crenulated ends of long bones and formation of cylinders characteristic of hyaena damage (Lyman, *ibid*, p.206); also tooth and scratch marks. There was evidence of spiral fracturing in some specimens (J. Lightwing, pers. comm.),

suggesting damage by trampling (Haynes, 1993). This argues for a period of post-mortem exposure for some carcasses before emplacement in sediment.

- A series of three hippopotamus vertebrae, in unrolled condition, were found elsewhere in the bone bed in a state of close articulation (J. Clayden, pers. comm.). The spine is typically the last part of the skeleton to fall apart according to the patterns of disarticulation for carcasses decaying in water (Mazza & Ventra, 2011, p.309). This argues for minimal transport of some carcasses to the site of primary deposition.
- Some teeth in the basal diamicton showed patchy diagenetic pyritisation, arguing for a period of burial in anoxic conditions (Turner-Walker, 1998).

Skeletal representation

- Examples of all classes of skeletal element were represented in the bone bed, from which we may infer that original death assemblages are likely to be present.
- A wide range of skeletal dispersal potentials is present, ranging from small bone fragments to an intact rhinoceros mandible (V#4). Although most of the bones were disaggregated before reaching their final resting place, on some occasions skeletal elements from the same individual were found close to one another (for example four rhinoceros ribs: T#4, T#8, T#9. T#10), and the instance of an articulated series of hippopotamus vertebrae as noted above. This argues for minimal transport between primary and secondary deposition sites, and against significant fluviatile sorting of elements.

Mortality profiles

- A mixture of juvenile, adult and old adult specimens were present. There was a preponderance of juveniles, especially *Bison* and *Hippopotamus*, suggesting a mixture of natural deaths and predator kills.
- Evidence of pathology was recognised in some specimens, notably osteoarthritis, mastoid abscess and malformation of teeth. Many pathological bones came from old adults, suggesting subsistence was easy and/or predator levels were low.

The site of primary accumulation for the vertebrate fossils of the bone bed may plausibly be reconstructed as a lake margin or a backwater swamp, part of which was subject to trampling by large mammals. Some carcasses were scavenged before burial, while others were put beyond reach of scavengers by rapid burial or having floated into the lake and disaggregated there. The presence of an interglacial lake at Shropham is attested by the sediments of Unit Sh-1, the *Chara* marl in which the bone bed was partly emplaced. It has been dated by RHUL to the early Ipswichian thermal optimum (see Appendix 2).

Marl lakes have alkaline waters, and are typically shallow, often with water depths < 5 m; they typically have a basin-like shape, with a small diameter compared with their area (Pentecost, 2009). In Britain, marl is typically deposited in them by precipitation of calcium carbonate ($CaCO_3$) out of groundwater through the biogenic action of charophytes (notably *Chara* sp.) and phytoplankton (Pentecost, *ibid*). At Shropham, the $CaCO_3$ is likely to have been sourced from springs arising directly from the chalk bedrock and/or indirectly from the chalk-rich Lowestoft Till of the valley side.

While marl lakes of Ipswichian age have not hitherto been recognised in Britain, *Chara* marls of early Hoxnian age have been recorded from several sites in Hertfordshire (Catt, 2010, p.158 ff). They are "*only produced during periods of climatic amelioration such as the late glacial interstadial and the Holocene*" (Pentecost, *ibid*, p.182), and *Chara* is "*an important component of the pioneer vegetation in shallow, newly formed lakes with clear, stagnant water rich in bicarbonate*" (Catt, *ibid*), all of which is consistent with an early interglacial age for the lake at Shropham. Its location on the margins of the Thet valley and its hydrology are congruent with a class of natural lakes in central East Anglia created by the effects of chalk solution and fed by alkaline groundwater rising from the Chalk bedrock, and which often have valley-marginal locations (West, 2009, p.18), of which Diss Mere is a notable example containing early Holocene marls (Peglar *et al*, 1984). Natural lakes may also be located in floodplains, for example three palaeo-lakes of late Devensian age identified in the headwaters of the adjacent Little Ouse and Waveney catchments (Tallantire, 1969), and which may be attributed to the melting of buried bodies of spring-fed ground ice, dissolution of the underlying chalk or a combination of both (West, *ibid*, p.17).

The presence of a backwater swamp environment with evidence of fluvial input is attested by the organic-rich, fossiliferous, sands, silts and muds of Units Sh-2 and Sh-3 that are present overlying Unit Sh-1 at Site T. Marl deposition evidently ceased as the rate of chalk solution slowed, the lake became shallower and more fluvial and terrestrial conditions succeeded as the interglacial progressed.

The parent deposit

Unit Sh-4 is the result of a complex sedimentological history, in which Ipswichian lacustrine and backswamp deposits became mixed with black angular and sub-angular flint clasts to form a diamicton. The details of the genesis of this parent deposit for the bone bed are unclear from the information presently available; however, it is likely to have taken place in a cold climatic period, when fresh, frost-shattered flint was locally available. The lack of abrasion displayed by the bones indicates that they did not travel far before incorporation in the diamicton. The flint could have been introduced by fluvial agency, which may account for a proportion of flint having a sub-angular index of rounding. It may also have been introduced by solifluction or by mass movement, for example a mudslide caused by saturation of the periglacial active layer by rainfall or a thaw event (Ballantyne & Harris, 1994, p.118). Solifluction diamictons of Devensian age have been recognised at Beetley in the upper Wensum catchment (West, 1991; p.81). If Unit Sh-4 is correctly correlated with RHUL Li-12, the formation of the diamicton is likely to have taken place in the period of climatic deterioration that immediately followed the Ipswichian Stage, attributed to early MIS 5d (see Table A2.1) and termed the Herning or Melissey I Stadial (Mangerud, 1989, 1991), dateable to circa 110,000 BP ((Lowe & Walker, 1997, p.330).

The secondary depositional context

The bone bed represents the secondary depositional context for the fossil material. It is interpreted as the result of a sediment gravity flow (SGF), defined as a mixture of water and sediment particles where gravity acting on the sediment particles moves the fluid, in contrast to rivers, where the fluid moves the particles. SGFs are catastrophic subaerial or subaqueous events that may originate from the sliding of an unstable sediment mass on a slope (Postma, 2011); their rheology is described by Postma (1986). Dynamism is evident in the undulating and convolute bedding seen at the

dipping interface between units A and B, and intra-formationally in the alternating sub-facies of unit B (Figs 7 and 14): it is also evident in the disturbed bedding of the underlying unit A (Fig. 13). The predominant azimuth orientation of the skeletal elements and the cuspate microfolds indicate flow was in a south to south-easterly direction, towards the axis of the Thet valley.

The products of turbulent, low concentration, cohesionless flows are contrasted with those of laminar, highly concentrated, cohesive flows to provide a spectrum classification of SGF on the basis of flow characteristics during the depositional phase. Cohen (2003) discusses SGF in lacustrine settings. Turbidity flow is '*the most common gravity flows in lakes ...initiated where sediment-charged underflows moved down a sloping surface, or through the partial resuspension of unstable soft sediment on a slope*'. By contrast, a debris flow is a '*type of gravity flow that often leaves deposits along the flanks of steep sided lakes. Debris flows are extremely dense, water-saturated flows that exhibit plastic flow behaviour and have sufficient internal strength to keep very large particles, even boulders, aloft. Whereas turbidity flows are highly turbulent, debris flows move in a laminar fashion... depositing massive, unstratified layers of debris*" (p.68). Unit B in Sections Y and Z displays characteristics of both cohesionless turbidity (fluidal) and cohesive debris (plastic) flow; indeed many cohesive flows show characteristics of turbulence at some stage in their evolution (Lowe, 1982, p.293). Sub-unit B^1 is here interpreted as the result of a high-density, cohesive, laminar debris flow in a subaqueous setting which introduced diamictic sediments into the basin under the influence of gravity, while B^2 is interpreted as evidence of phases of more turbid, cohesionless flow that introduced similar sediment from which the mud fraction had been winnowed by the current, perhaps indicating input from pulses of water rather than debris slurry. A subaqueous context for the whole deposit may be inferred from this evidence for alternating phases of more and less turbulent flow (see Fig. 14). The host water body may have been a deep river channel, but is more likely to have been a lake occupying the site of the early Ipswichian marl lake, re-activated *in situ* when chalk solution processes resumed in the early Devensian.

Contortion in the bedding of the underlying unit A may have been synchronous with the SGF event, and hence the result of partial liquefaction and remobilisation. Vertical 'veins' of pale sediment, visible in Figure 13, extend through unit A upward

into unit B, and are interpreted as water-escape structures as a response to the loading of the superincumbent unit. The emplacement of the bone bed is interpreted as the result of a SGF event that remobilised the bones from their place of primary deposition and entrained them a relatively short distance downslope. The duration of this event is likely to have been quite short, perhaps a matter of minutes. The greater concentration of bones in the lower and proximal part of the flow may be interpreted as evidence of a basal traction carpet of larger, more hydrodynamically-resistant clasts in the fluidised sediment, while the flint clasts remained equally dispersed and supported within its matrix. The horizontal position of many of the elongated bone elements may reflect a degree of laminar shear along the basal layer during transport (Mazza & Ventra, *ibid*). The incorporation of several bones into unit A and the vertical emplacement of Z#6 in it are considered evidence of partially fluidised conditions in the flow's sedimentary substrate, Unit Sh-1.

Sediment gravity flow has been recognised in an interglacial lacustrine context at Beetley (West, 1991, p.14). Here, calcareous lacustrine silts and marls of early Hoxnian interglacial age were overlain by a wedge of silty clay with flint pebbles and seams of sand, followed by deposition of further marls. This was interpreted as a landslip into the lake basin. Evidence for subaqueous SGF has also been recognised in the early Hoxnian lacustrine sequence at Mark's Tey, Essex (West, *ibid*, p.23; Turner, 1970).

The receptor environment

As discussed above, the receptor environment for the flow event(s) is likely to have been a lake. Evidence for the presence of such a water body immediately postdating the emplacement of the diamicton, and possibly therefore its depositional context, was identified by the RHUL team in their Profile 11. A sequence of fine-grained sands and silts (SH-Li13 and 14) were interpreted as mineral matter inwashed at a lake margin or a slow-flowing river (Walkling, 1996, p.140). Coloepteran evidence (SH-C7) indicates that this took place in an intensely cold continental (tundra) environment of arctic severity, with mean January temperatures of between -25 and -27°C (Walkling, *ibid* p.166). If so, we can speculate that the debris flow event(s) occurred during the height of the earliest Devensian cold substage, MIS 5d. This dating is constrained by the evidence for a *terminus ante quem* presented below.

Unit Sh-5 (upper gravels)

Unit C (Sh-5) is bedded more or less horizontally and unconformably over unit B (Sh-4), and was deposited following an erosive event that truncated the sedimentary sequence in Area Y, thus removing physical evidence for the source area of the vertebrate material and the SGF. It is here correlated with RHUL unit SH-Li17, characterised as cross-bedded, yellow, coarse gravels and cobbles transported by a high-discharge river. Two bones recovered from this horizon were in rolled condition. The pollen, coleoptera and mollusca from SH-Li17 were not sampled by the RHUL team; however the underlying unit SH-Li-16, a peaty mud, was sampled, and the coleopteran assemblage was labelled SH-C8 and interpreted as indicating a cool temperate climate that was correlated with MIS 5c, the Chelford Interstadial (Mayle *et al*, *ibid*; Fig. 9), dateable to circa 96,000-103,000 BP (Lowe & Walker, *ibid*, p.332). The erosive event marked by the base of unit C clearly postdates this stage, and may be attributed to a later cold period. A possible candidate would be the following stage 5b, the Rederstall or Mellisey II Stadial (Behre, 1989; Mangerud, 1991), dateable to circa 91,000 BP, during which global sea levels fell more than 50 m below those of the present (Lowe & Walker, *ibid*, p.332, 333). Unit C (Sh-5) represents the initiation of a major period of aggradation in the River Thet valley during which the basal units of Terrace 1 were deposited. The beds overlying unit C (including Units Sh-6 and Sh-7) comprise the uppermost strata of this terrace, but are not further discussed here.

Dynamic factors triggering the SGF

Theoretical factors governing debris flows include instability in the source debris, gradients necessary for initiation and a trigger mechanism (Colcutt, 1986). A range of causal factors were discussed by West (*ibid*, p.23) when considering a landslip identified in early Hoxnian sediments at Beetley: instability caused by local artesian water pressures; collapse associated with solution of the underlying Chalk; earth tremor; fluctuations of water level in a steep-sided basin. Several possible scenarios may be advanced to explain the triggering of the bone bed diamicton into a subaqueous SGF at Shropham.

- *Basinal subsidence*. Slumping of a lake-marginal sediment stack, for example a lacustrine feeder delta, might have been brought about by subsidence in the sedimentary basin. The role of groundwater-induced solution and collapse of Chalk bedrock has been identified as a formative geomorphological factor at several East Anglian lake sites. Examples of sites include Diss Mere (Peglar *et al. ibid*), Quidenham Mere (Peglar, 1993) and the class of doline lakes known as Breckland meres (Bennett *et al.* 1991). The role of chalk solution is invoked by Cox (1985) to explain the accumulation of a thick sequence of Ipswichian sediments on the valley floor at Elsing. It is also a causative factor in the sporadic occurrence of subsidence holes in adjacent parishes, as at Rockland (Bennett, 1884) and as seen by the author in a field at Snetterton in 2009. It is identified as a factor disturbing terrace deposit sequences in the Thames valley, through features ranging from steep-sided pipes to cone-shaped hollows with a diameter of between 50 and 100 m (McGregor & Green, 1983). Calcium carbonate solubility at the Earth's surface is promoted by wet conditions, enhanced by acidity from soil organic activity (McDowell *et al.* 2008). Cold and wet conditions would also promote dissolution, such that chalk solution could have occurred during much of late Pleistocene. Regardless of the exact timing, sink holes are likely to have developed beneath terrace sediments on the valley floor, some possibly quite large, leading to subsidence and possibly triggering a SGF event.
- *Sediment loading*. Destabilisation of a lake-marginal body of sediment could have been triggered by the loading of a subaerial body of debris (for example soliflucted material, flood gravel, landslide or mudflow) onto it, leading to sudden slope failure. The transport of a fossil-bearing terrigenous deposit into a palaeolake in the Italian Appenine Mountains is discussed by Mazza & Ventra (*ibid*), and is attributed to the impact of a landslide. Despite the low relative relief of the adjacent valley slopes (sloping at approximately 2.6 degrees at present), such a scenario could have been possible at Shropham because debris flows can take place on slopes as gentle as 1 or 2 degrees (Reading, 1978, p.378), and slope failures triggered by rapid thawing of the permafrost active layer can take place on gradients of between 2 and 5 degrees (Ballantyne &

Harris, *ibid*, p.118). The diamictic nature of the sediments of Unit Sh-4 could be attributed to such processes.

- *Marginal upwarping.* Instability could have been induced if a lake-marginal sediment stack were destabilised by localised upwarping of the lake margin. Such upwarping can be brought about through periglacial diapirism, as proposed for Devensian floodplain sediments at Roosting Hills Pit, Beetley (West, *ibid*, p.79). Upward injections of water-saturated sands and gravels, some with a balloon-like form, occurred here at the margins of basins or channels, and were interpreted as having been generated by localised releases of hydrostatic pressure associated with the development or decay of permafrost; they are linked with the development of solifluction sheets (*ibid*, p.81). Artesian pressure from a hydrostatic head in the Chalk aquifer was considered to be a related factor. At Shropham, evidence for localised upwarping affecting sediments adjacent to Area Y and antedating the emplacement of the upper gravels (Unit Sh-5) was seen in Section E immediately north-west of Area Y (see Appendix 3), and may have been sufficient to trigger a SGF event in an unstable body of lake-marginal sediment.
- *Seismic activity.* A seismic event would be another potential trigger for a SGF (West, *ibid*, p.23). Earthquakes with a magnitude (general size) 4.0 are generally required to trigger landslides (Jibson, 2012). Catastrophic fracturing of Ipswichian speleothem deposits in Kent's Cavern, Devon, has been attributed to '*a substantial earthquake*' dated by Uranium Series and ESR techniques to the early Devensian Stage, between 100,000 and 75,000 BP (Straw, 1997). The Sula Sgeir Fan off the coast of northwest Scotland is thought to have been formed by a debris flow triggered by an earthquake '*probably just before or during the early Devensian, i.e. around 70,000 years BP*' (Musson, 2008a). It is possible that an earthquake of magnitude 7 in this location could have generated magnitude 3 tremors in East Anglia or Kent's Cavern (Musson, *ibid*, fig.2), and there is an outside possibility that it may have been sufficient to trigger a SGF event. However, there is evidence of earthquakes of sufficient intensity (strength of shaking) to trigger landslides happening in East Anglia and the North Sea basin in historical times. For example, an intensity 6 earthquake in East Anglia in 1165 was sufficient to knock people off their feet

and ring church bells; an intensity 8 event centred on Norwich in 1480 damaged church spires and caused building collapse (Musson, 2008b); another significant event occurred near Colchester in 1884 (Musson, 2007). The largest recorded British earthquake occurred offshore near the Dogger Bank in 1931, with a magnitude of 6.0 and an intensity of 3 to 4 (Wikipedia, 2015). Similar events are statistically likely to have happened in the early Devensian, and could theoretically have been sufficient to trigger a SGF at Shropham.

THE GENESIS OF THE BONE BED - CONCLUSIONS

Reviewing the evidence presented above, the following scenario is thought most likely for the genesis of the Shropham bone bed.

1) The presence of a marl lake developed in a chalk-solution hollow on the floor or margin of the Thet valley during the early phases of the Ipswichian interglacial (MIS 5e).
2) The presence of a lake marginal or backwater swamp environment containing organic-rich muds were the primary depositional context in which vertebrate remains accumulated.
3) The presence of a lake during the opening phase of the Devensian Stage, with its likely origin in resumed down warping of an existing chalk-solution hollow.
4) The admixture of coarse, clastic material derived from fluvial or solifluctal sources into the interglacial muds under cold conditions, likely to have taken place during the opening phases of the earliest Devensian stadial (MIS 5d). This formed the parent deposit for the bone bed.
5) An episode of lake marginal instability. The causal factors cannot be resolved in this study, but could include chalk solution, differential sediment loading, localised diapiric upwarping under hydrostatic pressure, seismic activity - these acting singly or in combination.
6) Subaqueous slumping of the parent deposit by sediment gravity flow into the lake basin; deposition of Unit Sh-4, with concentration of vertebrate remains into the bone bed by fluid dynamic processes; likely to have taken place in MIS 5d.

7) Removal of the source area for the SGF by an erosional episode affecting Area Y, probably due to fluvial action eroding sediments exposed by upwarping in that locality. This was followed by deposition of Unit Sh-5, representing a cold-phase aggradation of braidplain gravels, possibly during MIS 5b, and forming the foundations of Terrace 1 in the Thet valley.

Concluding remarks

Shropham is one of a number of richly fossiliferous sites spanning the Ipswichian and early Devensian stages in East Anglia. Such sites include Barrington (Gibbard & Stuart, 1995), Beetley (McWilliams, 1972; West, 1991), Bobbitshole (West, 1957), Coston (Lightwing, 1983); Itteringham (Hallock *et al*, 1990), St Ives Galley Hill (Preece & Ventris, 1983), Lynford (Boismier *et al*, 2012); Saham Toney (N. Larkin, pers. comm.); Swanton Morley (McWilliams, *ibid*; Coxon *et al.*, 1980), Wortwell (Sparks & West, 1968) and Wretton (Sparks & West, 1970). Ipswichian lacustrine and fluviatile deposits are well-represented in the region due to their preservation as 'buried terraces' beneath later floodplain aggradations. While many amateur and professional geologists and palaeontologists have investigated Shropham since the 1950s, and have been astounded by the quantity and quality of the environmental evidence to be found in its successive quarries (P.L. Gibbard, pers comm.), pitifully little information about this wealth has been published. Little information, either, has been published about the geology and geomorphology of the River Thet valley.

This report presents 'rescue' information about the composition and geological context of the bone bed as revealed in temporary exposures at Manor Farm Pit between April and June 1994. Clearly Shropham is an important palaeontological site, if only because it has yielded the first continuous sequence of fossiliferous deposits from Britain spanning the entire Ipswichian and transition into the Devensian (Mayle *et al*, *ibid*). From the point of view of the vertebrates, the bone bed may be described as a *'bulk sample'* of a middle Ipswichian fauna (A. Read, pers comm.), and so has little value for detailed palaeoecological studies about this interglacial. In this respect, Shropham is *'the site that got away'* (J. Lightwing), and although we have a wealth of fossils in various collections, it is largely unsupported by geological analysis and thus reminds us of the contextual information that has now been lost for ever. Sadly, the sense of wonder at the vertebrate palaeontological possibilities felt by all who visited

the site was not matched, at the time, by ways and means to record and research it. While the results of the rescue recording outlined in this paper may tell us little we do not already know about the Ipswichian, they do have something to say about the early Devensian environment, and in particular the likely role of chalk solution and periglacial diapirism in local sedimentary basinal dynamics and the taphonomic accumulation of reworked vertebrate fossils.

This paper is the first account devoted to placing the rich fossil vertebrate heritage of this quarry in a more precise geological context. Drawing on research by RHUL, it attempts to make wider chronostratigraphic correlations, and thus sheds light on environmental conditions in the River Thet valley in the Ipswichian / Devensian transition and early Devensian stages. Hopefully it will provide an impetus to other workers to publish their findings, however incomplete, so that the story of this extraordinary site can be told more fully. Hopefully it will allow specimens from Manor Farm Pit in Norwich Castle Museum to be placed in a better-understood chronological context, and will inform research into late Pleistocene sediments underway at Saham Toney in the adjacent Wissey catchment (Nigel Larkin, pers comm.). It should also remind us that 'rescue geology' is worthwhile, often adding to the sum total of our knowledge about past environments and inspiring new research.

FUTURE WORK

- Sediment samples collected during this investigation and others by the Database Group have yet to be analysed for fossil plant, coleopteran and molluscan content. This may enable more accurate stratigraphic correlation with the results of RHUL research.
- Large bovid specimens need further examination to improve identification to species level (*Bos primigenius* or *Bison priscus*), following the work of Gee (1993).
- The results of other work by members of the Database Group would augment the palaeontological findings of this report. The results of geometrical surveying by V.J. Banks would permit the local datum to be related absolutely to Ordnance Datum. The results of section logging by A.J. Read would permit the stratigraphy of Area Y and Area U to be related to sites elsewhere in the pit, and these sites to be related to RHUL stratigraphy, so allowing specimens collected by J.R. Clayden, J. Lightwing, C.R. Stephenson and others to be provenanced to bed level. It would

also allow the basic stratigraphy, outlined here, to be refined. Combining the results would allow a set of measured composite sections to be drawn, to permit the geometry of the various sedimentary units to be understood in greater detail and place the bone bed in wider geological context.

- Industrial minerals assessment borehole data may enable a three-dimensional model of the subsurface geometry of the Thet valley, to provide a generalised picture of the thickness and distribution of sediments and the contours of the buried Chalk surface. However, British Geological Survey mineral assessment borehole data is not currently available for the Thet valley, and the present site owner, Breedon Aggregates Ltd, does not hold any borehole records from previous owners.
- A large quantity of Shropham vertebrate material has been deposited with the Norfolk Museums Service by various collectors over the years, but has not yet been accessioned (D. Waterhouse, pers comm.). This includes material deposited by the present author in 1994. Accessioning and cataloguing would help secure the usefulness of the archive for scientific research.
- Bison specimens from Shropham at the British Museum (Natural History) are currently being investigated for evidence of tuberculosis by Prof David Minnikin (Institute of Microbiology and Infection, School of Biosciences, University of Birmingham), with promising results (D. Minnikin, pers. comm.). Given the range and quantity of Shropham vertebrate material in various collections, there is potential for carrying out future palaeopathology work for this and other diseases.

THE EXCAVATION ARCHIVE

Most of the palaeontological material from the Database Group excavations in 1994 was deposited at Norwich Castle Museum (NCM), where it received remedial conservation treatment by Gordon Turner-Walker using the consolidant resin Paraloid B-72.

- Site X – 6 specimens
- Section Z – 17 specimens
- Section Y – 10 specimens
- Area U, Site V – 1 specimen

Paper copies of site plans and other excavation records were also deposited at NCM. It is not presently possible to give the Museum's accession numbers for this material, however the rhinoceros mandible #V4 has been accessioned as NWHCM: 2005.306.

The remaining vertebrate and plant specimens and sediment samples from the sections described in this paper are retained by the author, pending possible transfer to the Museum. He retains digitised copies of the photographic records. All specimens have been catalogued in the Blackwell Science 'Idealist' database (v.Nov95), from where information can be exported to other programmes via tab- or comma-delimited formats. Information about photographic records is also included in this database. Where appropriate, fossils have been consolidated using dilute polyvinyl acetate (PVA) solution.

A large body of other palaeontological material from Shropham is archived at NCM; the details of which were until recently available online: 'Collections Online for All' database at http://www.culturalmodes.norfolk.gov.uk/projects/nmaspub5.asp [accessed August 2014]. This service was suspended in 2015, pending relaunch on a new digital interface (D. Waterhouse, pers. comm.).

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APPENDIX 1

COMPOSITE FAUNAL LIST FOR MANOR FARM PIT

including species from both Ipswichian and Devensian contexts.
Compiled by J. Lightwing from information correct to September 1995.

Pisces	*Anguilla anguilla* (L.)	eel
	Esox lucius L	pike
	Gasterosteus aculeatus L.	three-spined stickleback
	Perca fluviatilis L	perch
Amphibia	*Bufo bufo* L	common toad
	Rana temporaria L	common frog
Reptilia	*Emys orbicularis* L	European pond turtle
	Vipera berus L.	adder
Aves	*Anas platyrhynchos* L.	mallard
Mammalia	*Insectivora*	
	Sorex araneus L.	common shrew
	Rodentia	
	Apodemus sylvaticus L	wood mouse
	Arvicola terrestris L.	water vole
	Castor fiber L.	beaver
	Clethrionomys glareolus (Schreber)	bank vole
	Microtus sp.	a vole
	Lagomorpha	
	Lepus sp.	a hare
	Carnivora	
	Canis lupus L.	wolf
	Crocuta crocuta (Erxleben)	spotted hyaena
	Meles meles (L.)	badger
	Panthera leo (L.)	lion
	Ursus arctos L.	brown bear
	Vulpes vulpes L.	red fox
	Proboscidea	
	Mammuthus primigenius Blumenbach	woolly mammoth
	Palaeoloxodon antiquus Falconer & Cautley	straight-tusked elephant
	Perissodactyla	
	Coelodonta antiquitatis Blumenbach	woolly rhinoceros
	Dicerorhinus hemitoechus (Falconer)	narrow-nosed rhinoceros
	Artiodactyla	
	Bison priscus Bojanus	a bison
	Capreolus capreolus (L.)	roe deer
	Cervus elaphus L.	red deer
	Dama dama (L.)	fallow deer
	Hippopotamus amphibius L.	hippopotamus
	Megaceros giganteus (Blumenbach)	giant deer
	Sus scrofa L.	wild boar

APPENDIX 2
STRATIGRAPHIC WORK BY STUDENTS AT ROYAL HOLLOWAY, UNIVERSITY OF LONDON

Fourteen geological profiles (sections) were identified by Royal Holloway University of London (RHUL) students in summer 1994 as comprising a basic stratigraphic succession through the sedimentary sequence at Manor Farm Pit. Heights were surveyed to a temporary bench mark arbitrarily set at 100 m.

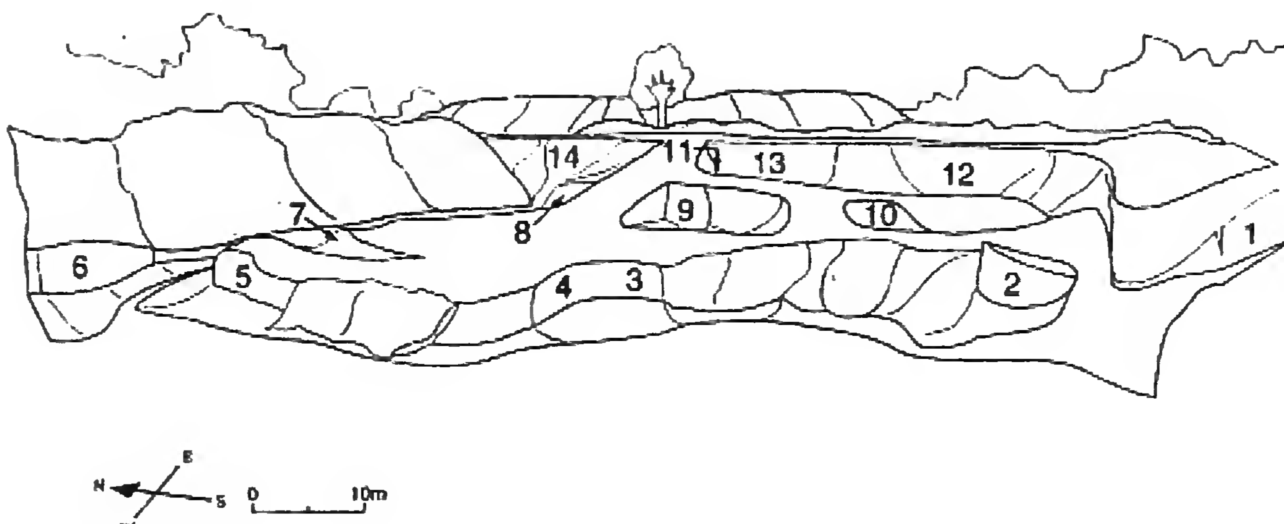

Fig. A2.1. Field sketch showing RHUL (Profile) locations, July 1994, viewed across the pit looking south. Adapted from Walkling (1996, figure 5.3). (Note: points of the compass are incorrectly given in this diagram: north should have been east; east, south, and so forth.)

A composite lithostratigraphy of 19 units was constructed (SH-Li1 to 19) by P.L. Pieruccini. A biostratigraphy of 8 coleopteran faunal units (SH-C1 to 8) was identified, spanning the end of MIS 6 through to the Chelford Interstadial (MIS 5c) (Walkling, 1996), and also 11 molluscan biozones (SH-BZM1 to 10) (Dixon, 1997). A biostratigraphy of five pollen zones for Profile 11 in the Pit was also identified, spanning part of the upper stratigraphic sequence (Mayle, quoted in Walkling, *ibid*). A vertebrate faunal list was supplied by J. Clayden and J. Lightwing, distinguishing species distribution above and below SH-Li10. The results of this research were presented at the 9th International Palynological Congress at Houston, USA, in June 1996 (Mayle *et al*, 1996).

A summary of the stratigraphy, with chronology and a synthesis of palaeoenvironmental data, is provided by Walkling (*ibid*).

The base of the sequence was Chalk rubble (SH-Li1). This was overlain by chalky, yellow, coarse sands, grey gravels and organic-rich sands and silts (SH-Li2, 3 and 4) dipping steeply (20° to 30°) towards the south-east. SH-Li4 is correlated with the early Ipswichian transition by reference to its coleopteran fauna. It was overlain by horizontally-bedded lacustrine laminated sediments (SH-Li5) grading upwards into a massive pale green clayey silt (SH-Li6), the lacustrine *Chara* marl, that is correlated with the Ipswichian thermal optimum (mean July temperature 21°C). This marl provided a marker horizon in the lower part of the Pit, and was overlain by a sequence of fossiliferous deposits that are also attributed to the thermal optimum: fluvially-deposited, grey, shelly sands (SH-Li7); lacustrine / backwater brown organic-rich silts containing seed pods of *Trapa natans* (SH-Li8); grey shelly sands and gravels (SH-Li-9).

These beds are overlain by deposits associated with climatic cooling into the Ipswichian / Devensian transition: coarse gravels with organic silt inclusions (SH-Li10) representing a fluvial reworking of SH-Li9, grey sandy gravels (SH-Li11), a diamicton-like unit of grey poorly sorted sands with dispersed pebbles identified as a localised debris flow (SH-Li12), and fine grey well-sorted sands (SH-Li13).

Deposits correlated with an early Devensian cold stage on the basis of their arctic tundra fauna are represented by a thick unit of horizontally-bedded, grey-brown sands and silts (SH-Li14) and coarse grey sands and gravels (SH-Li15). The uppermost part of the sequence was formed by fine, detrital, black organic mud with peaty inclusions (SH-Li16), identified as having been deposited in floodplain conditions during a period of climatic amelioration (tentatively correlated with the Chelford Interstadial). This unit was overlain by 2-3m of coarse, yellow, cross-bedded gravels and cobbles (SH-Li17) deposited by a high-discharge, fast-flowing river. Horizontally-bedded, coarse, yellow sands (SH-Li18) representing floodplain sediments capped the sequence.

Correlation with sediments of the bone bed

The RHUL team did not sample and analyse any of the sediments of the bone bed in Section Y and Area U. However it is possible to make correlations between the Database Group (DG) stratigraphy and the RHUL stratigraphy based on RHUL Profile 10, located adjacent to Area U and which spanned units SH-Li 6 to SH-Li12 (Table A2.1). For the uppermost strata (Unit Sh-5), the key is provided by RHUL Profiles 11 and 14 located against the quarry's southern wall. More precise correlation is subject to the following limitations.

1) Although sediment samples of the bone bed have been collected, they have not yet been analysed for coleoptera, mollusca or pollen, thus preventing absolute correlation with the RHUL biostratigraphy.

2) The relative positions of the RHUL sections were surveyed to a temporary bench mark but not to Ordnance Datum, impeding lateral correlations between sedimentary units displayed in them and those in the Areas recorded and sampled by the Database Group. This may not be so surprising in the circumstances of a working quarry, in which the physical geography of geological exposures and spoil heaps changed on a weekly, if not daily, basis.

Table A2.1. Correlation of Database Group and RHUL lithostratigraphies.

Sections / Sites	Unit	Lithology	DG stratigraphy	RHUL stratigraphy
Sections Y and Z	C	Sands & Gravels	Sh-5	SH-Li 17
	B	Grey diamicton	Sh-4	SH-Li 12
	A	*Chara* marl	Sh-1	SH-Li 6
Area U, Site T	B	Grey diamicton	Sh-4	SH-Li 12
	A^2	Grey shell-rich sands	Sh-2	SH-Li 7
	A^1	Brown silty clay	Sh-1	SH-Li 6
Area U, Site V	B	Grey diamicton	Sh-4	SH-Li 12
	A^2	Grey shell-rich sands	Sh-2	SH-Li 7
	A^1	*Chara* marl	Sh-1	SH-Li 6

3) There are inconsistencies in the RHUL stratigraphy, especially in the middle parts of the sequence. For example, reading from figures 5.13 and 5.14 of Walkling (1996), lithological unit SH-Li10 may be correlated with coleopteran unit SH-C6 in Profile 11, but SH-C4 in Profiles 8 and 9; if so, its sediments were deposited in the cool Ipswichian/Devensian transition period in Profile 11 but the Ipswichian optimum in Profiles 8 and 9. This is clearly problematic. Similarly, SH-Li12 may be correlated with coleopteran unit SH-C7 in Profile 11 but SH-C6 in Profile 9; if so, its sediments were deposited in the early Devensian interstadial in Profile 11 but the Ipswichian / Devensian transition in Profile 9. It is likely that these problems have arisen because of mislabelling of lithological units in the field. The identification of discreet units in Manor Farm Pit was particularly difficult in the absence of clear marker horizons in middle to upper parts of sequence. It is likely that intense lateral variability of facies due to fluviatile reworking of sands, gravels, and organic silts in this part of the sequence during the early Devensian led to confusion between superficially similar sediments. The difficulty of erecting molluscan biozones in such circumstances was explicitly highlighted by Dixon (1997, chapter 7): *'The mixing of sediments within any fluvial system may lead to mixing of molluscan species from different environments, and may be represented in the fossil record as samples with a number of species from different environments and climatic regimes'.*

It is considered that the RHUL stratigraphy can successfully be used for correlation with the Database Group stratigraphy, provided that Profiles 8 and 9 are treated with great caution. Profile 11 is particularly useful, as it spans units SH-Li7 to SH-Li15 and is supported by a pollen diagram spanning the later Ipswichian to early Devensian (MIS 5e to 5d).

Units	Lithol	Interpretation	Pollen	Interpretation	Coleop	Interpretation	MIS	Bonebed
SH-Li17	Upper gravels	High-discharge river	Information not available		Information not available		[5b]	Sh-5
SH-Li16	Peaty muds	Floodplain deposits	SH11-5	Calluna heathland	SH-C8	Cool temperate climate, marshy environment with trees	5c	n/a
SH-Li15	Grey gravels 3	Fluvial						
SH-Li14	Grey-brown sands & silts	Lacustrine or fluvial backwater	SH11-4	Alder, oak and hazel – possible mild phase	SH-C7	Very cold continental climate, open ground, treeless environment with water bodies	5d	
SH-Li13	Fine grey sands	Lake margin or slow river						
SH-Li12	Grey sands with dispersed pebbles	Debris flow	SH11-3	Open ground, with grasses and herbs; pine & birch woodland. *Pediastrum* algal peak.				Sh-4
SH-Li11	Grey gravels 2	[Fluvial]						
SH-Li10	Brown organic silts with gravels	Fluvial			SH-C6	Cold continental climate, open ground environment with some coniferous woodland		n/a
SH-Li9	Grey shelly sands and gravels	Lacustrine or fluvial backwater	SH11-2	Open ground, with grasses & herbs; sparse pine & birch woodland	SH-C5	Cool temperate climate, stagnant water body with coniferous woodland	5e	
SH-Li8	Brown organic silts	Lacustrine or fluvial backwater			SH-C4	Warm temperate climate, stagnant, vegetated water body		Sh-3
SH-Li7	Grey shelly sands	Fluvial	SH11-1	Hazel, oak, birch, pine woodland	SH-C3	Warm temperate climate, forested bog and swamp habitats		Sh-2
SH-Li6	Chara marl	Lacustrine	Information not available					Sh-1
SH-Li5	Laminated silts & clays	Lacustrine			SH-C2	Warm temperate climate, complex of aquatic habitats in the vicinity of a water body		n/a

Table A2.2. Correlation of bone bed lithostratigraphic units with RHUL stratigraphies, including palaeo-environmental interpretations and indicative correlation with Marine Isotope Stages. (Information derived from Walkling 1996 and Mayle *et al*., 1996, fig. 9).

APPENDIX 3

QUARRY WESTERN EXTENSION, JULY 1994

In July 1994 the quarry was extended at right angles to, and about 20 m NE of, Section Y, creating Section E (Fig. 5), and the face was progressively worked in a southerly direction at right angles to Section Y. The resultant exposures (Figs A3.1-A3.3) provided a useful opportunity to examine its sedimentary context. It partly corresponds with RHUL Profile 1 (Fig. A2.1).

Section E exposed a coupled anticlinal/synclinal structure with a wavelength and amplitude of approximately 3.5 m and 2 m, and an axis trending approximately N-S. The geology of this exposure was logged by the RHUL team (Walkling, *ibid*, pp.133, 134), though not its tectonic details. The lowermost unit was a bed of sand (identified as SH-Li2 of pre-Ipswichian age) forming the core of the anticline. The eastern limb of the anticline was formed by a steeply-dipping (c.30°), apparently conformable sequence of gravels (SH-Li3) and organic-rich sands and silts (SH-Li4) underlying laminated lake sediments of early Ipswichian age (SH-Li5). Its western limb was coupled with a slightly asymmetrical synclinal structure containing a dark grey, contorted diamicton resembling Unit Sh-4. The crest of the anticline was later truncated by horizontally-bedded, coarse sands and gravels, recorded by the Database Group as Unit Sh-5 [SH-Li17].

As the quarrying progressed southwards along the strike of the anticline, the structure could be seen to broaden out, and an extensional crack or ice-wedge cast was revealed on the anticlinal crest. In this area, superincumbent sediments on the eastern limb were identified by the Database Group as the diamicton Unit Sh-4 [SH-Li12] and overlying units (Fig. A3.3).

These structures are evidence of tectonic disturbance to bedding in the area immediately north-west and west of Area Y, and the dipping bedding evident in Sections Y and Z (cf. Fig. 9) is clearly part of this tectonic scenario. As far as the timing of the folding is concerned, we can state that it antedated the deposition of the upper gravels of Unit Sh-5.

Periglacial ground-ice activity is a plausible explanation for the disturbance. The basal sands may be interpreted as having undergone plastic deformation and diapiric updoming while in a water-saturated state; this may have been brought about by injection of groundwater under artesian pressure beneath developing or decaying

permafrost (Washburn, 1973, p.154) or of groundwater in the active layer trapped beneath frozen ground or a solifluction sheet (Ballantyne & Harris, *ibid*, pp.69, 70). Pressurised groundwater is likely to have been available at this site in the early Devensian, given the local proximity of the Chalk aquifer and the local hydraulic gradient transferring groundwater from the valley side south-eastwards towards the centre of the Thet valley.

Fig. A3.1. Section E, composite photograph, July 1994, eastern end, looking south. Anticlinal structure (right) and location of datum post for bone bed excavation (arrowed) at north end of Section Y. Scale: 1 metre.

Fig. A3.2. Section E, composite photograph, July 1994, western end looking south. Synclinal structure containing chaotically-bedded, organic-rich sands and silts, with descending limb of anticlinal structure (left). Scale: 1 metre. Note: the vertical line (tonal contrast) in the section seen equidistant between the spade handle and scale is an artefact of photographic stitching.

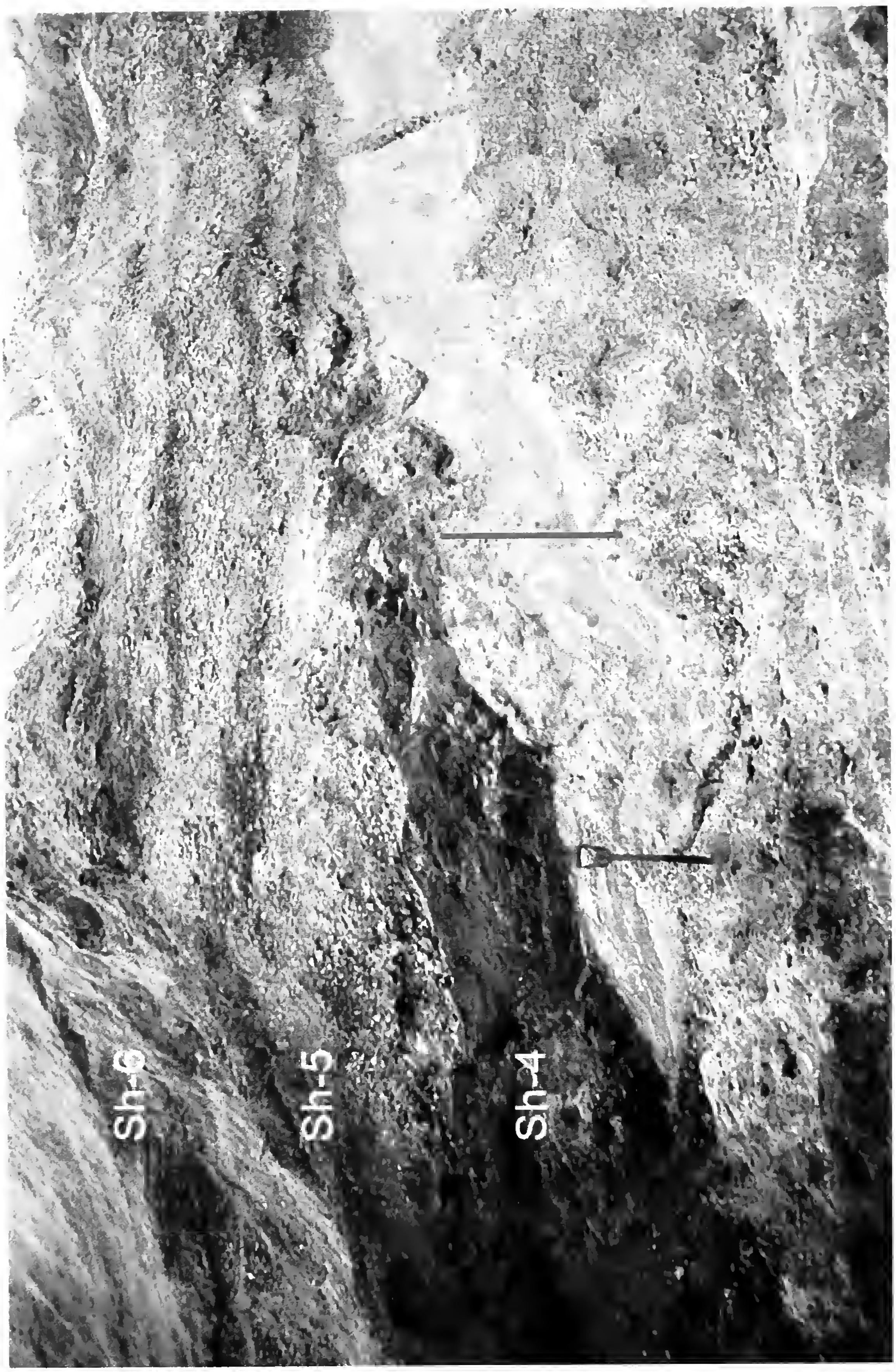

Fig. A3.3. Progressed quarry face about 10 m south of Section E, later July 1994, showing anticlinal structure in the area behind Section. Note presence of ice-wedge cast or crack structure in anticlinal crest on far right. Scale: 1 metre.

CONTENTS

The Geological Society of Norfolk exists to promote the study and understanding of geology in East Anglia, and holds meetings throughout the year. For further details consult our Web Site (http://www.norfolkgeology.co.uk) or write to Martin Warren, General Secretary of the Geological Society of Norfolk, Chesterfield Lodge, West Street, Cromer, Norfolk NR27 9DT.

Copies of the Bulletin (including older back copies) can be obtained from the editor at the address on p.1; it is issued free to members.

The photograph on the front cover is from Shropham pit (Section Y, June 1994) as detailed in the article by Holt-Wilson in this issue of the Bulletin. A cluster of specimens in the bone layer include a wood fragment in close association with a bovid metatarsal.

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